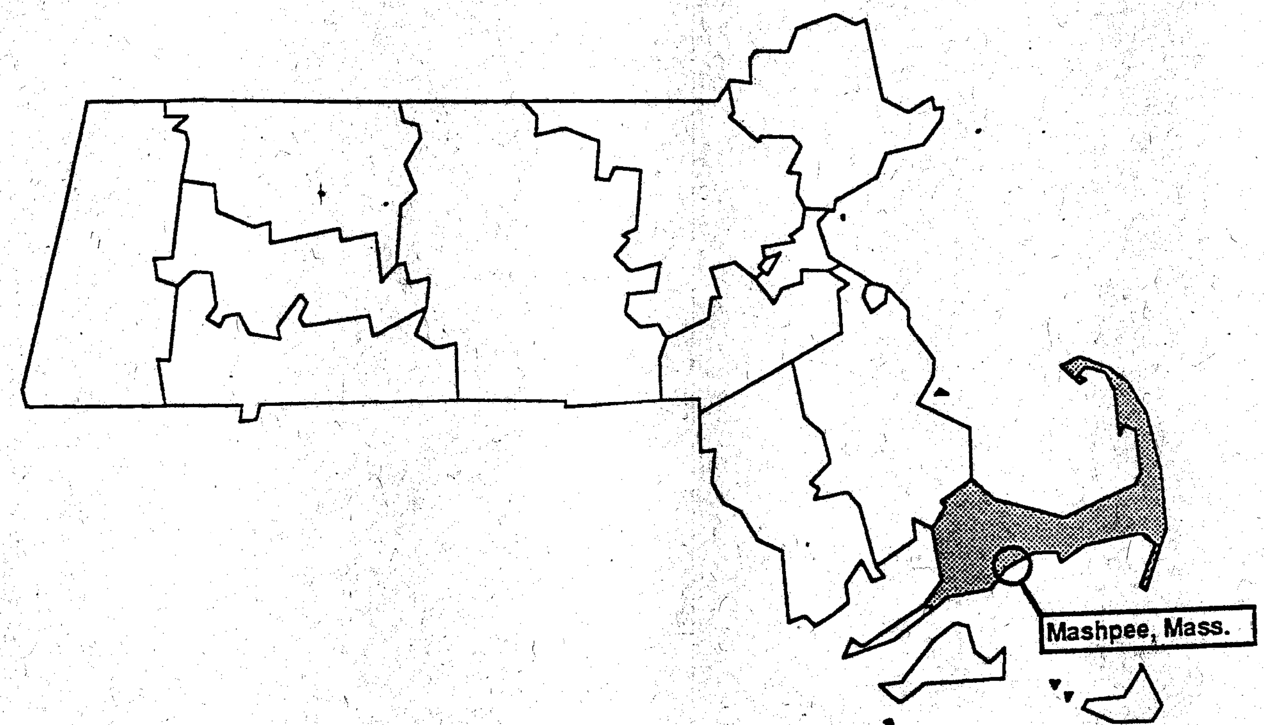
Mashpee, Massachusetts

Sea Level Rise Impact Investigation



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13. ABSTRACT *(Maximum 200 words)*
The study reviews the most current technical literature on sea level rise effects and predictions as well as focuses on determining the potential for increased flooding. The report provides an updated hydraulic analysis and an analysis of flooding impacts on land, structures, and the salt marsh for the coastal community of Mashpee, Massachusetts. Sea level rise increments of 1,2,3,6 and 9 feet were selected as increments representative of the various sea level rise scenarios. Determined from the hydraulic analysis, the 1-2 foot range of sea level rise was chosen as the adequate model for short term (next 40 years) effects of sea level rise. The study found that as the magnitude of sea level increases, wave height and wave runup would create a greater effect contributing to an increased risk of coastal flooding. This report suggests that regulatory agencies such as the Massachusetts Coastal Zone Management (MCZM) should consider the effects of sea level rise both for the short term (30-40 years) and long term (100 years).

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EXECUTIVE SUMMARY

This sea level rise impact investigation was accomplished by the Long Range Planning Branch, Planning Directorate, New England Division, U.S. Army Corps of Engineers at the request of Massachusetts Coastal Zone Management (MCZM). The study was funded under the authority provided by the Corps of Engineers' Section 206 Flood Plain Management Services (FPMS) program. The study reviews the most current technical literature on sea level rise effects and predictions as well as focuses on determining the potential for increased flooding. The study provides an updated hydraulic analysis and an analysis of flooding impacts on land, structures, and the salt marsh for the coastal community of Mashpee, Massachusetts.

The study found that since many factors affect sea level rise and because of the diversity of sea level rise predictions, it is crucial to understand the inherent uncertainty involved. To overcome some of this uncertainty, several sea level rise projections were compared over a time frame of 100 years. For the most part predictions were consistent with historic trends for the first 40 years after which there were some sharp disparities. In addition, this study focused on a range of sea level rise for the updated hydraulic analysis rather than select any particular model. Sea level rise increments of 1, 2, 3, 6 and 9 feet were selected as increments representative of the various sea level rise scenarios. The 1-2 foot range of sea level rise corresponded to the historic trends. Other more drastic sea level rise projections were highly variable and ranged typically from a few feet to 9 feet and greater.

As a result of the updated hydraulic analysis, it was determined that the 1-2 foot range of sea level rise would provide an adequate model for short term (next 40 years) effects of sea level rise wheresas the 3-9 foot range was a good indicator of the more severe impacts (more likely to occur 100 years in the future) due to sea level rise. Generally, the study found that as the magnitude of sea level increases, wave height and wave runup would create a greater effect contributing to an increased risk of coastal flooding. However, this study found that assessing the impacts of sea level rise is an extremely site specific endeavor, dependent on such other factors as slope, topography and landuse. For instance, the 1-2 foot range of sea level rise will mainly affect low lying areas whereas when the sea level rises to 6-9 feet there will be significant impacts for both flat, low terrain beaches and steep cliffs. At these levels, many areas that normally would not be affected by the 100-year coastal storm event will experience increased flooding. Moreover, rising sea levels could impact groundwater supply and could affect the development of saltwater marsh. Without more detailed site specific analysis, saltwater marsh is expected to be able to maintain current historic levels under the historic 1 foot per 100 year relative sea level rise.

This study found that sea level rise will increase flooding impacts and have a resultant influence on social, political, economic, and environmental concerns. Therefore, to address these concerns and plan for future development , it is first necessary for those local and state governmental agencies responsible for managing the coastal zone to create a strategy for developing planning policy. This study provides a model to assist in the decision making process. This study suggests that regulatory agencies such as the MCZM should consider the effects of sea level rise both for the short term (30-40 years) and long term (100 years). However, from a practical standpoint , this study recommends that the MCZM should focus its resources on the 1-2 foot range analysis, more representative of short term impacts, in developing planning policy for future development. Reliance on a predictive model more consistent with historic trends is more practical and defendable because of the availability of supportive data.

Furthermore, this study recommends that in addition to the new hydraulic analyses provided by this case model of Mashpee, state agencies within the Commonwealth of Massachusetts and local communities develop a comprehensive resource inventory database. A successful resource inventory will facilitate in evaluating the effects of sea level rise on a particular resource. Moreover, because much of this information is already available from the Commonwealth on their Geographic Information System (GIS), creation of this comprehensive resource inventory may not require a considerable amount of effort. The resource inventory in conjunction with the model provided by this study will help policy makers make informed decisions, enabling them to formulate strategies for reducing or mitigating the effects of sea level rise in a community or state. Although, this report recommends focusing on the 1-2 foot range in sea level rise, in the interim, actual sea level rise should continue to be monitored and the public informed of potential future impacts.

Sea Level Rise Impact Investigation
Mashpee, Massachusetts

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MASHPEE, MASSACHUSETTS

I. Introduction

A. Background

This study is in response to concerns of the Masssachusetts Coastal Zone Management (MCZM) regarding future effects of increased sea level rise on coastal communities in Massachusetts. MCZM initially provided three (3) potential coastal communities for this study of which Mashpee, Massachusetts was selected for the reasons discussed later in this report. This study also involved a review of technical literature on current sea level rise projections. MCZM is particularly interested in this sea level investigation in order to facilitate the process of evaluating future state policies for development along the coast. The study will provide assistance to the state in long range planning to ensure that natural resources, public health and safety are properly protected.

B. Authority

This study was initiated by the New England Division, U.S. Army Corps of Engineers, Planning Directorate, Long Range Planning Branch (LRPB) for Massachusetts Coastal Zone Management. The study was funded under the authority provided by the Corps of Engineers' Section 206 Flood Plain Management Service (FPMS) program.

C. Purpose and Scope

The purpose of this investigation is to estimate the future limits of the 100-year coastal flood boundaries based on various increments of rise in sea level for the community of Mashpee, Massachusetts. The study provides a description of pre-flood conditions in terms of land characteristics and identifies various sea level rise projections, an updated hydraulic analysis and presents maps illustrating the effects on the 100-year flood limits. The report also discusses qualitatively the effects on land, structures and saltwater marsh.

II. Project Study Area

A. Location/Community Selection

Initially, MCZM identified three (3) coastal communities as potential candidates for studying the effects of sea level rise. The suggested communities were: 1) Mashpee; 2) Westport; and 3) Dennis (Cape Cod Bay side). Each community was evaluated based on topographic, land use and environmental characteristics and the availability of necessary data for the analysis.

Mashpee was selected as the most appropriate study site because existing data needed for the analysis was more readily available than the two alternatives. In addition, Mashpee possessed a variety of natural resources as well as developmental characteristics considered critical for this investigation. The community contained saltwater marsh areas, coastal dunes and banks, both A and V floodplain zones as well as developed and undeveloped areas. In general, A zones are areas inundated by the 100-year flood. V zones represent coastal high hazard areas inundated by the 100-year flood which have additional velocity hazards associated with waves of 3 feet or greater. Of particular significance was the presence of both flat terrain beaches governed by wave height and steep cliffs controlled predominantly by wave runup.

B. Sea Level Rise Projection

1. Background

The scientific community has recognized concerns over the potential impact that long term sea level rise could have on the coastal environment and economy. Some authorities have argued the contrary view, asserting that the earth is entering a new ice age and sea level is dropping. However, based on a cursory review of recent literature on this subject, the predominant view suggests that sea level is increasing. Scientific researchers have suggested that increased human activities have lead to elevated atmospheric concentrations of carbon dioxide and other gases. These gases in turn have caused a warming of the earth contributing to the sea level rise over the last century.

Among the consequences of global warming or cooling will be higher sea levels and changes in precipitation patterns. Global cooling or warming will create more extensive and rapid accumulation or melting of ice and snow in alpine and/or polar regions and actual contraction or expansion of upper ocean waters. These "greenhouse effects" will contribute to increases in "absolute" global sea level. However, because of the dynamic nature of the earth's atmosphere, ocean, global crustal motion and local crustal motion, global sea level rise is not evenly distributed throughout the earth. Because changes in sea level cause a change in vertical elevation of the oceans measured with respect to a known reference point on the land, landward motion will be an important consideration. Consequently, relative or local sea level provides a better indicator for trends in sea level rise for planning purposes. In addition, because the coastal zone is often characterized by low flat terrain, increased elevations of sea level will have a significant impact on horizontal changes in the shoreline.

Consideration of historic trends in sea level rise is often used in hydraulic studies because they provide the best indicator of future trends versus predicted values. For instance, the historic data for New England indicates that sea level elevation is rising. In the National Research Council's (NRC) publication, an examination of some of the recent trends is made. Based on a figure from the NRC publication, the best estimate for the relative sea level rise for Mashpee, Massachusetts is about 2.3 millimeters (mm) per year, the same estimate for Woods Hole, Massachusetts (See Figure 1). Giese et al have investigated shoreline recession due to relative sea level rise. In considering this issue, Giese focused on the passive retreat of coastal uplands in Massachusetts due to sea level rise. Relative sea level rise for the coast of Massachusetts has been between 2 to 3 mm/year over the past 60 years (Aubrey & Emery, 1983). This increased level has been due to both coastal submergence and absolute sea level rise. It should be noted that coastal submergence is attributable to both sea level rise and local subsidence. Based on existing tide gage data, local subsidence or land sinking in Massachusetts has been documented to contribute 1.9 mm/year which accounts for about two thirds of the coastal submergence. Local subsidence in Massachusetts is due primarily to the oscillation of the land mass from the release of the glacier's weight. Because Massachusetts is located on the terminal end of a major glacier, glacial melting will cause these ends to subside.

2. Discussion of Various Sea Level Rise Projections

There are a diverse number of projections made by scientific researchers on the magnitude of sea level rise. A popular approach was provided by Hoffman who developed various sea level rise scenarios based on low and high assumptions of all the major uncertainties (Hoffman, 1983). It should be noted that Hoffman's data does not include land movement, which in Massachusetts is an important consideration. The major factors accounted for include: thermal expansion of ocean waters, melting of mountain glaciers, melting of Greenland glaciers and Antarctic ocean glaciers (NRC, 1987). Estimating the significance of these various processes will require an estimate of global warming. Hoffman's projections illustrate the complexity involved in modeling the future trends of sea level rise. Moreover, because of difficulty in modeling certain factors as well as modeling unknowns, projections have to be revised. Hoffman revised earlier projections to include updated snow and ice melting effects, accounting for glacial process models not present in his previous projections (Hoffman, 1986).

This variability and interrelationship of factors involved in sea level rise make it difficult to predict an accurate level. As illustrated by the Hoffman models, there is a wide range of possibilities for sea level rise depending if one looks at short term effects (over the

From National Research Council, Marine Board, 1987,
"Responding to Changes in Sea Level: Engineering Applications,
p. 10, Figure 1-1.

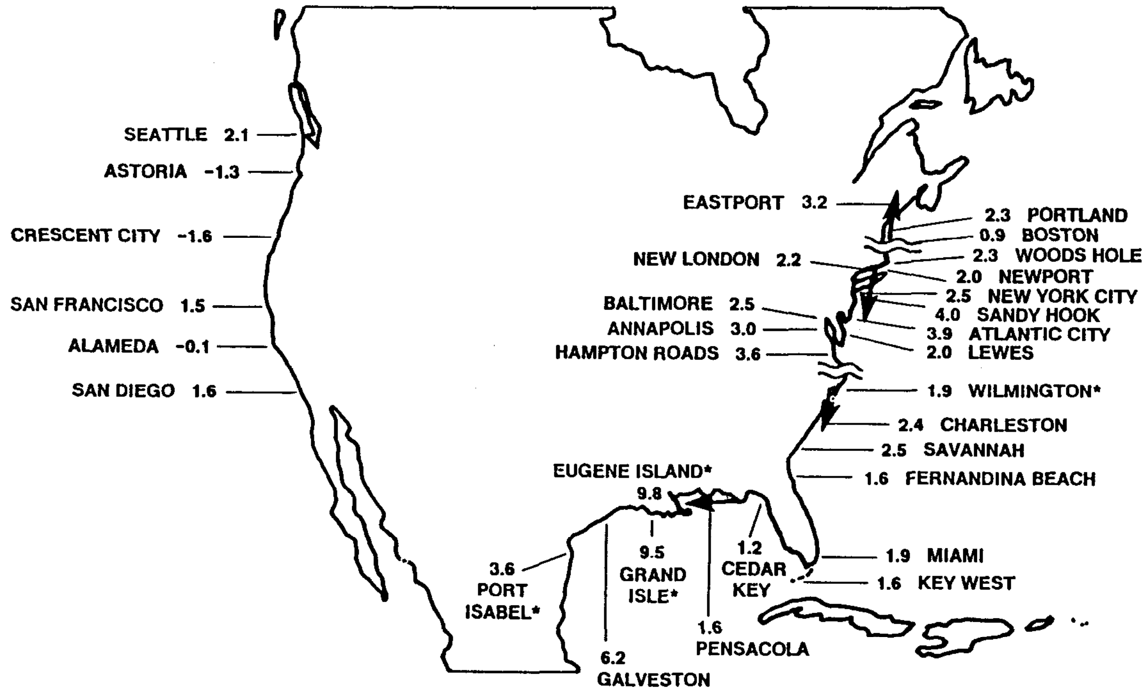


FIGURE 1-1 A summary of the present best estimates of local relative sea level changes along the U.S. continental coastline in mm/yr. The figures are based on the tide gauge records over different intervals of time during the period 1940–1980. Much regional variability is evident. Source: Adapted from Stevenson et al. (1986).

FIGURE 1

next 30 to 40 years) or long term effects (over the next 100 years). For example, Hoffman's models at year 2080 show a range of 1.5 to 9.0 feet sea level rise whereas at year 2000 less than 0.5 foot sea level rise is predicted. Hoffman's models also do not consider the effects of local subsidence, a crucial factor when the magnitude of sea level rise is minimal or when land movement is significant as it is in Massachusetts.

3. Methodology for Selection of Sea Level Rise Scenario

Because prediction of future sea level rise is such a precarious proposition with many resulting implications, relying on a particular scenario is inappropriate. In addition, the study found that greater emphasis should be placed on historic sea level rise trends for long range planning purposes. Corps of Engineers policy indicates that until evidence to demonstrate otherwise is found, the local or regional history trends should take precedence. However, states such as Maine and Massachusetts (draft policy) have included some additional increment of potential sea level rise in regulatory or policy requirements. For example, Maine requires a 3 foot consideration in their Sand Dune regulations and Massachusetts "draft" policy requires a 1 or 3 foot consideration based on the life expectancy of the proposed structure of activity.

Some degree of compromise was necessary in deciding whether to use a purely historic sea level rise or one of the many predictive models. There were three primary criteria that both the New England Division and MCZM wanted to consider: 1) sea level rise which took into account the effects of local subsidence; 2) a model which provided projected levels that were in the mainstream of other estimates; and 3) historic trends for a given area. All these various scenarios were plotted and analyzed for a time period of 100 years. A duration of 100 years was judged to be a long enough period in which to perform the analysis (See Figure 2). As the graph illustrates, the local subsidence rate of 1.9 mm/year (0.006 ft/yr) as documented in MCZM report entitled "Massachusetts Coastal Submergence

Program: Passive Retreat of Massachusetts Coastal Upland Due To Relative Sea Level Rise" (Giese et al., 1987) was factored into the analysis. Likewise, the current/historical rate of 2.9 mm/year (0.009 ft/yr) was plotted. Based on literature research, particularly estimates as found in Table 2-1 and Table 2-2 , page 27 of "Responding to Changes in Sea Level". Hoffman's low and high projections were determined to be appropriate for our analysis. Hoffman's projections provided a broad and representative range for sea level rise. As illustrated by Figure 2, the historic rate with local subsidence and Hoffman's low projection are close approximations. (Note: In Figure 2, local subsidence was factored into the Hoffman projections.) However, after year 2035, the difference between Hoffman's high projection and the other rates of sea level rise increases dramatically. Because there is as much uncertainty in the models, it was decided not to choose one particular model to follow.

The initial study approach was to analyze the potential effects of sea level rise occurring every 20 years, however, after the review of the sea level rise projections, it was determined that such an approach would create too many variations. Instead, the approach used was to select specific incremental changes in sea level elevations over the study period. Based on Figure 2, sea level rise increments of 1 foot, 2 foot, 3 foot, 6 foot and 9 foot were selected as the increments representative of the various sea level rise scenarios. By selecting these specific elevations, one could easily correlate these levels to the different projection and time periods. For instance, in Massachusetts, Hoffman's low projection predicts a rise of about 2 feet occurring in the year 2090 whereas this same elevation may occur at year 2050 under Hoffman's high projection. Increments less than 1 foot were not used due to the limitations of the available contour mapping and the accuracy of the hydraulic analysis.

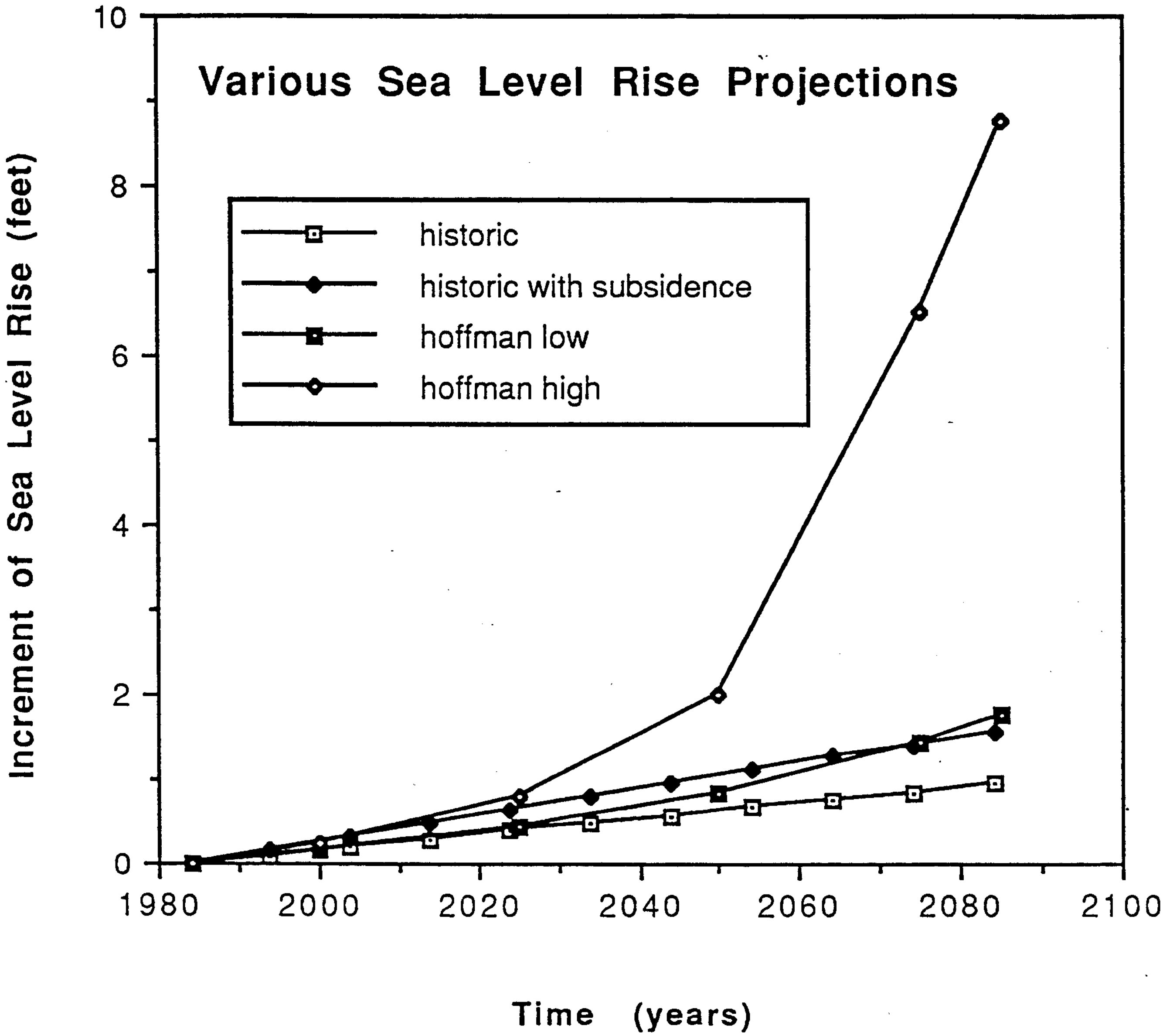

Various Sea Level Rise Projections
historic
historic with subsidence
hoffman low
hoffman high
Increment of Sea Level Rise (feet)
0
2
4
6
8
10
1980
2000
2020
2040
2060
2080
2100
Time (years)

FIGURE 2

III. Hydraulic Analysis
A. General

Based on the factors discussed in the previous section, the hydraulic analysis examines several whole foot incremental changes in sea level. Besides providing a more flexible approach to the comparison of sea level rise projections, it limits the number of computer runs for the hydraulic analysis to a more manageable level of effort.

This study focuses primarily on the increased flooding levels and flood zone limits resulting from rising sea level. Therefore, it would be necessary to compare the existing 100-year coastal flood limits to the new limits created by the different sea level rise scenarios. Because this study would provide assistance for long range planning, the current analysis used in developing the National Flood Insurance Program (NFIP) 100-year flood limits was required to establish the initial base condition. Moreover, because changes in the modeling methodology have been made since the Flood Insurance Study was published, the delineations were updated to the current Federal Emergency Management Agency (FEMA) criteria. Specifically, the hydraulic analysis was updated to account for FEMA's new criteria for treating the effects of coastal dune erosion.

Two types of wave processes govern hydraulic analysis of coastal flooding for this investigation. First, a wave height analysis was performed to determine wave heights and corresponding wave crest elevations for areas inundated by tidal flooding. Secondly, a wave runup analysis was performed to determine the height and extent of runup beyond the limit of tidal inundation. The results of these analyses were combined into a wave envelope, which was constructed by extending the maximum wave runup elevation seaward to its intersection with the wave crest profile. The methodology is described in detail in "Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping", Third Draft, Federal Emergency Management Agency (FEMA), July 1989.

1. Erosion Assessment

Because coastal sand dunes may not be durable due to massive shorefront erosion occurring during a 100-year flood, an erosion assessment must be performed at each location investigated prior to initiating the wave height and runup procedures. Storm-induced erosion will remove or significantly modify most frontal dunes on the U.S.A. Atlantic and Gulf shores. To account for frontal dune erosion, FEMA developed an approximate procedure whereby a frontal dune is assumed to be able to withstand the 100-year storm provided that the frontal dune reservoir has a typical cross sectional area of at least 540 square feet above the 100 year stillwater elevation. If a dune has a frontal dune reservoir less than 540 square feet, storm induced erosion is expected to obliterate the existing dune with sand transported both landward and seaward.

2. Wave Height Analysis

The wave height methodology is based on procedures originally developed by the National Academy of Sciences (NAS) and described in its 1977 report entitled, "Methodology for Calculating Wave Action Effects Associated with Storm Surges." Three major concepts form the basis of the NAS methodology. First, a storm surge on the open coast is accompanied by waves and the maximum height of these waves at any point is directly related to water depth. Secondly, natural and man-made obstructions will dissipate energy; thereby, diminishing breaking wave height. Thirdly, throughout unimpeded reaches between obstructions new wave generation can result from wind action which adds energy; increased wave height being related to distance and mean depth over the unimpeded reach. Wave height analysis was conducted using FEMA computer program "Wave Height Computations for Flood Insurance Studies," Version 3.0, September 1988.

3. Wave Runup Analysis

Stone and Webster Engineering Corporation developed the procedures for wave runup analysis in its "Manual for Wave Runup Analysis, Coastal Flood Insurance Studies", November 1981. It is essentially a composite slope runup procedure relying heavily on data developed by the Corps of Engineers for presentation in the "Shore Protection Manual." The FEMA computer program "Wave Runup," Version 2.0 was employed for this study.

B. Methodology

The first step in conducting the hydraulic analysis for this study was to perform a thorough review of relevant information including the "Flood Insurance Study (FIS), Town of Mashpee, Massachusetts," dated 5 December 1984, and related backup from wave analysis completed by Anderson Nichols and Company (ANCO) in August 1983. Most of this backup information from the original FIS was obtained from the Commonwealth of Massachusetts, Department of Environmental Management (DEM) files. Computer input from these backup files was used for the updated hydraulic analysis. A field investigation was conducted along the entire Mashpee shoreline to become familiar with physical features impacting the flood hazard analysis.

Although it is not the intent of this study to revise the established Mashpee FIS, it was necessary to determine the effect of the latest FEMA wave height, wave runup, and erosion criteria on existing flood zones in order to form a basis for comparison of hypothetical sea level rise scenarios. Since the ANCO analysis was completed prior to implementation of the latest FEMA procedures, it was determined that alone it would not serve as an adequate reference data base.

The base flood or 100-year stillwater level used for existing conditions was that presented in the published Mashpee FIS. This level is in agreement with more recent studies conducted by the Corps of Engineers and presented in "Tidal Flood Profiles - New England Coastline," September 1988. A wave height and wave runup analysis was performed on all seven transects presented in the original 1984 study. Levels used for existing and sea level rise scenarios are shown in Table 1. Sea level rise conditions were developed in even foot increments to simplify the hydraulic analysis.

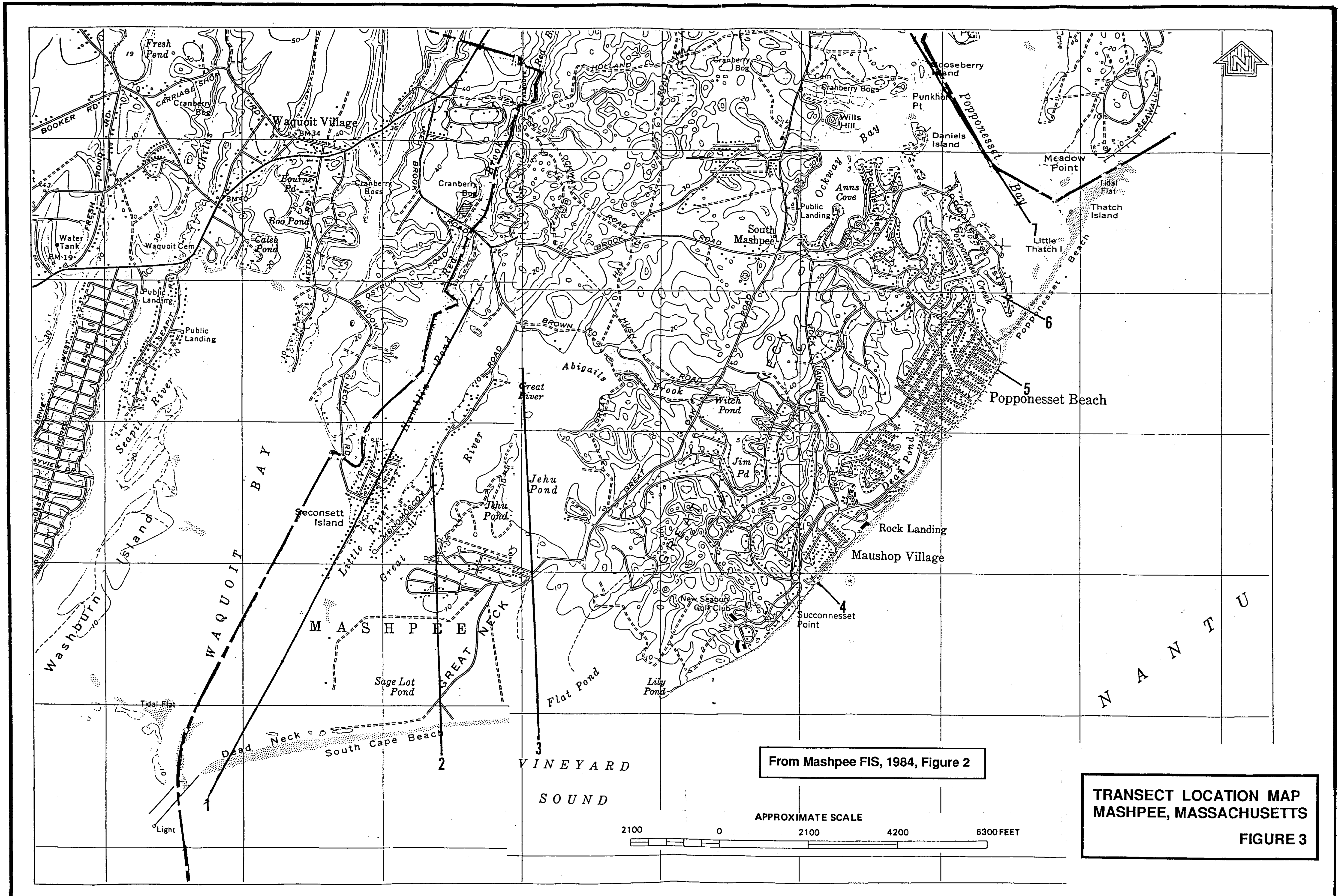
TABLE 1

BASE FLOOD LEVELS

	Sea Level Rise Condition (ft)	100-Year Stillwater Level (ft, NGVD)
	0-ORIG[1]	11.0
Baseline =>	0-NEW[2]	11.0
	1	12.0
	2	13.0
	3	14.0
	6	17.0
	9	20.0

Notes: [1] Refers to original 1983 ANCO FIS analysis.
[2] Original analysis modified for latest FEMA criteria.

Each transect was analyzed for frontal dune erosion conditions. This adjustment to the observed ground elevations was found appropriate for the low coastal areas near transects 1, 2, 3 and 6 (See Figure 3). In these areas the transects are fronted by a barrier beach dune along both South Cape and Popponesset Beaches. Since these dunes are already substantially overtopped by the existing base flood stillwater level, the erosion adjustment was relatively straightforward involving projection of an approximate 1 on 50 slope from the representative dune toe. The dune toe was estimated at about elevation 5 feet, NGVD for purposes of this evaluation. Engineering judgment combined with insights gained in a



TRANSECT LOCATION MAP
MASHPEE, MASSACHUSETTS

FIGURE 3

field investigation reinforced the assumption that significant dune erosion is likely during the 100-year flood. At transect 4, a very high eroding sandy bluff is present in the Maushop Village and New Seabury Estates area. Although continued and accelerated erosion of this area is likely during a 100-year flood today and with future sea level rise, no specific analytical predictive technique was determined to be appropriate for application within the scope of this investigation. Transect 5, along Popponesset Beach, is fronted by what appeared to be a fairly recently repaired or replaced revetment. The entire adjacent area showed significant use of structural erosion control measures such as groins and revetments. Should any of these measures experience undermining and failure during a major flood, significant shoreline erosion could occur. Analysis of the stability of these structural measures is beyond the present study scope. Mashpee Neck, transect 7, receives considerable protection from large ocean waves by the fronting barrier beach. With increased future sea level, erosion may become more problematic as larger waves reach the area due to increased water depth.

Some adjustments to the original ANCO transect geometries were necessary in order to conduct the analysis of erosion, wave height, and wave runup for existing and future sea level rise scenarios. Where discrepancies were found in backup data, assumptions were made based on best engineering judgement. Some transects were extended to accommodate the increased future sea level rise conditions. This was accomplished by extrapolation of the landward slope in conjunction with review of available mapping (See Figure 3: Transect Location Map). For continuity, the off-shore wave data determined by ANCO was carried throughout this study.

C. Results

With future sea level rise, larger and greater waves will be able to progress farther landward due to increased water depths. The net result will be a significant increase in wave crest profile and runup elevations. Increased wave energy will contribute toward added propensity for erosion in the coastal zone. A summary of the hydraulic results for each transect is provided in Appendix B, Table 2 . The table shows the elevation ranges for both the A and V zones for each sea level rise condition evaluated. Also displayed is the shoreward migration of the initial"A/V" zone interface for transects 1, 2, 3, and 6. The hydraulic analysis revealed that substantial shoreward migration of the initial "A/V" zone interface occurs when the ocean stillwater, resulting from sea level rise, overtops Seconsett Island, Great Neck, and Popponesset Island. At transects 4, 5, and 7 where wave runup is the primary factor of interest, the unadjusted height of runup was calculated. In the following section entitled "Transect Interpretation and Mapping," adjustments to these runup values to account for bluff overtopping are discussed. The increased runup and breaking wave forces will exert significant added erosional pressure especially in unprotected areas such as near transect 4. Plots of wave heights and runup for all transects for all cases analyzed are contained in Appendix A: Transect Profiles.

IV. Transect Interpretation and Mapping

A. General

In order to identify the impacts of sea level rise on flooding it was first necessary to analyze the results generated by the wave height and wave runup programs. The various scenarios were individually plotted and compared with the existing ground profile. The ground profile utilized was based on the published FIS with any required adjustments. In addition, prior to plotting wave height elevations on the transect profiles, the wave height elevations generated by the computer program were consolidated. Because of the large quantity of data generated from the calculations, it was impractical to plot all the data points. Moreover, plotting the additional points was not necessary since transects were supposed to be representative of large areas of land somewhat uniform in character.

Each scenario (i.e. 1 foot sea level rise) was plotted for each transect yielding 42 plotted profiles. Each transect profile was compared to the existing ground profile. Areas of inundation were identified on each profile and the 100-year coastal flood limit was delineated on 2 foot contour maps. The 42 plotted profiles were consolidated into seven (7) profiles for presentation purposes. In addition, output from the wave runup was plotted yielding the runup height above the water level. The maximum runup elevation was determined by adding the highest runup height for a given water level to that water level (See Appendix A: Transect Profiles).

Because of limitations of the wave runup model, special adjustments had to be made to determine the maximum runup. The wave runup model determines the maximum wave runup by calculating successive approximations of hypothetical slope until the generated wave runup heights differ by less than 0.1 foot. For some convex beach profiles and vertical seawalls the runup values will not converge. In this study, there were several situations where the wave runup program would not converge due to a convex profile. For Mashpee, there were low bluffs which extended up to a nearly level plateau. Because runup was increased with the addition of sea level rise, runup generated exceeded the bluff crest and therefore the program would not converge. For this situation, FEMA adopted a procedure developed by French (1982) for determining the realistic wave runup elevation, (See Figure 4). This study utilized this methodology. Moreover, the wave runup program often calculates a wave runup height which exceeds the maximum ground elevation because it requires the last positive slope to continue indefinitely. However, in reality the wave runup will overtop the maximum elevation and run off before reaching the computed elevation. Therefore, as recommended by FEMA, the maximum wave runup elevation was limited to 3 feet above the maximum ground elevation.

B. Inundation Mapping

Blue print originals of the working draft Flood Insurance Rate Maps developed in 1978 and 1983 were used in this study. The scales of these maps were adjusted so that all maps were at a scale of 1"=400'. Contours were at 2 foot intervals. Although, the maps differed somewhat from the final FEMA published FIS maps, these maps were the best available "original" contour maps. For the purposes of this study, the available contour maps provided a sufficient level of detail. One should note that it was never the intent of this investigation to remap the community of Mashpee or update the existing FIS. This study was not meant to supersede the published FIS, rather it was intended to address possible impacts of sea level rise that was not addressed or considered in the past study. Therefore, only the 100-year coastal flood limits were delineated. Other FEMA designated zones were not identified. The next section identifies particular areas of concern as well as discusses some of the flooding impacts.

V. Impacts of Sea Level Rise

A. General

Although, sea level rise will cause a multitude of impacts on the coastal shoreline, the potential impacts resulting from flooding is the primary focus of this study. Sea level rise will cause both greater areas of land to be inundated as well as elevated flood levels. Therefore, land which is presently in a minimal flood risk area will experience a greater risk from flooding as sea level rises. In addition, this submergence will influence landward migration of shoreline features such as wetlands and barrier beaches as well as the saltwater marsh zone. Sea level rise could also affect groundwater supply.

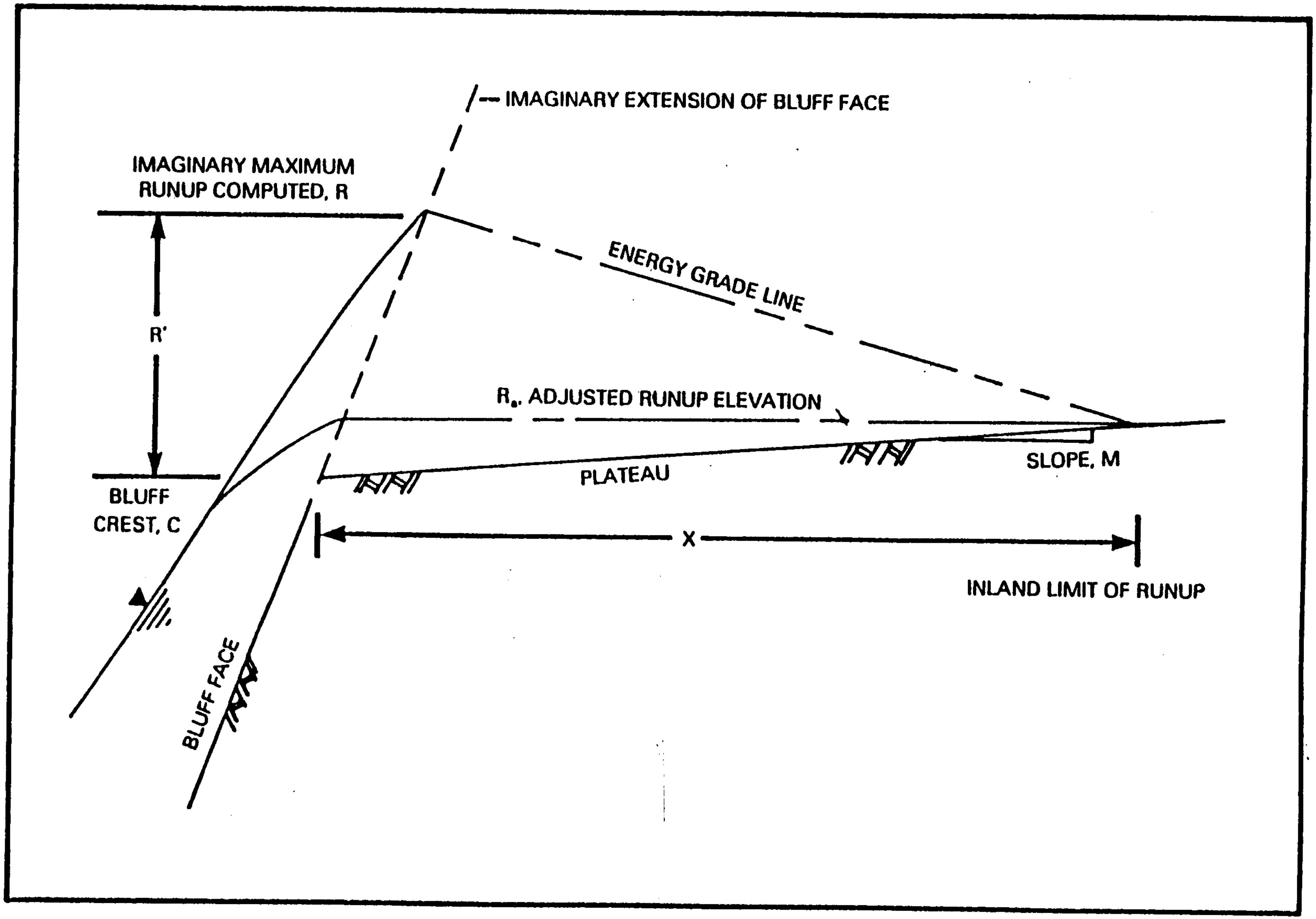
B. Identification of Potential Flooding Impacts

1. <u>General</u>

Flood delineations accounting for sea level rise reveal that generally the flatter sloped areas will receive the greatest impact on land use and structures. Certain areas such as in the Monomoscoy Road and Central Drive area will experience increased levels of flooding

FIGURE 4

From FEMA, "Guidelines and Specifications for Wave Elevation Determination and V-Zone Mapping", Third Draft 1989, p 51, Figure 12



Runup on Low Bluffs

both from greater flood elevations and wider flood limits. Figure 6 is an illustration of these impacts and shows the effects that increased sea level rise will have on 100-year coastal flood limits. The color shaded regions represent the additional areas of 100-year coastal flood plain for the various sea level rise increments. The non-shaded regions represent the baseline 100-year coastal flood limits without sea level rise. The existing 100-year flood limit extends from the shore and also includes areas adjacent to the rivers. As sea level rises from 1 foot to 9 foot, the area of the shaded regions increases illustrating wider flooding impacts.

The study also found that upper riverine areas will experience greater flooding because the flood limits are based upon stillwater elevations. Furthermore, because of elevated sea levels, wave runup effects will be more prevalent. The 100-year coastal flood delineations demonstrate that the amount of sea level rise directly influences the level of flooding. Generally, for a sea level rise of 1-2 foot, the landward inundation is slight. However, as the magnitude of sea level rise exceeds 3 feet, the inundated area increases dramatically.

In order to facilitate one's understanding of the flooding impacts for the various sea level rise increments, impacts will be divided into two major ranges: 1) 1-2 foot and, 2) 3-9 foot. A 1 foot sea level rise encompasses the historic trend whereas the 3-9 foot range represents a more drastic increase in sea level. Because of the limitations of the available mapping and level of detail provided by the analysis, flooding impacts due to sea level rise were grouped into ranges. Moreover, for the most part additional landward inundation between the 1 foot and 2 foot increments was minimal.

2. Transect 1
1-2 Foot Range

At the Monomoscoy Road and Central Drive area near transect 1, a 2 foot sea level rise will completely submerge the Monomoscoy Road area (See Figure 6). Since both the

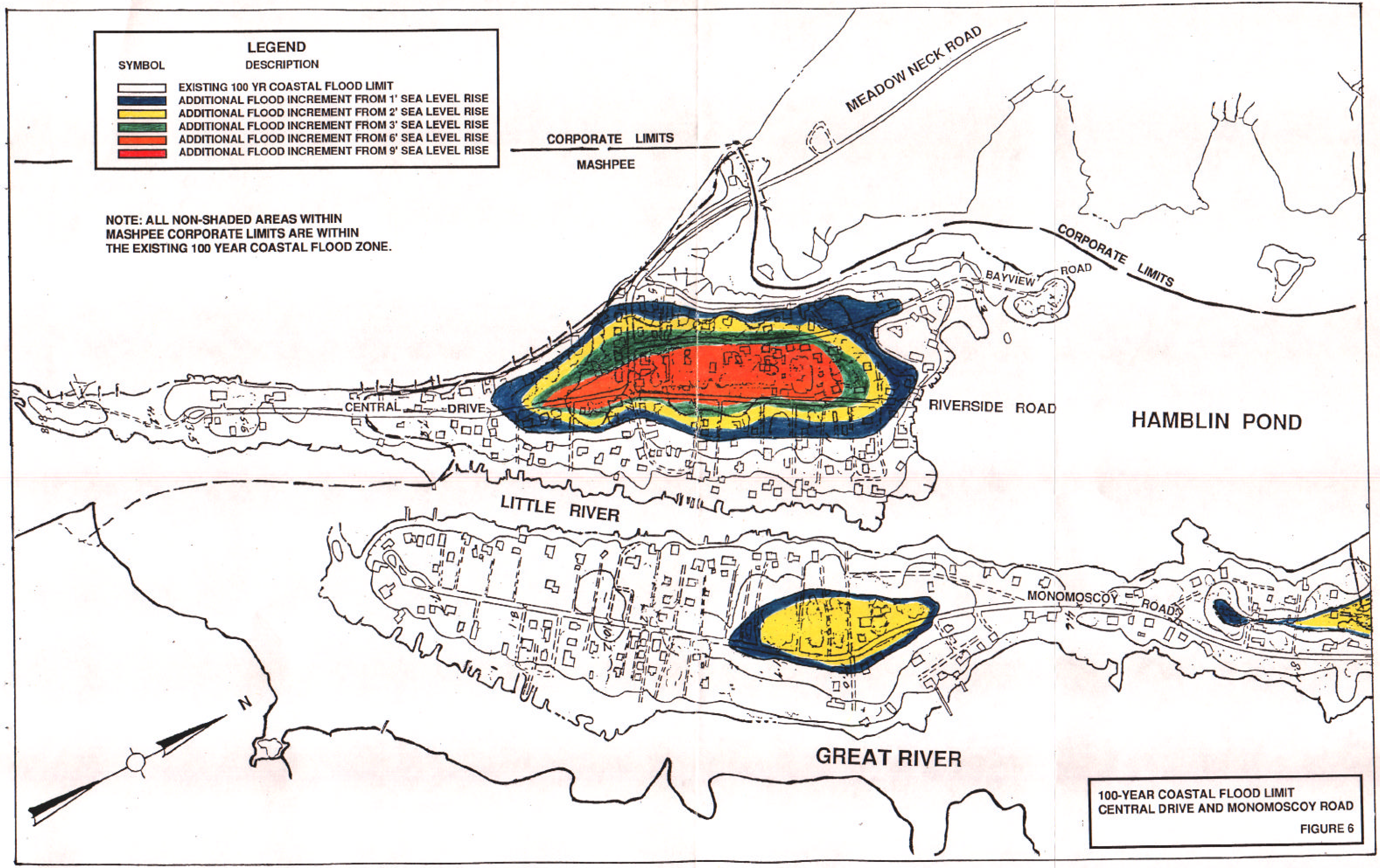
Monomoscoy Road and Central Drive area are primarily developed with residential dwellings, inundation of the area will cause considerable flooding of structures. For upland riverine areas beyond the Central Drive area, the stillwater elevation defines the flood zone limit. At the 1-2 foot range, the stillwater elevation does not vary much, however, riverfront properties may experience additional flooding.

<u>3-9 Foot Range</u>

At the 3-9 foot range, the sea level rise will significantly increase both the magnitude and area of flooding near Monomoscoy Road and Central Drive. Portions of Central Drive will be inundated when sea level rises to 3 feet. Complete inundation of the Central Drive area will result when sea level rises to 6 feet . Moreover, because the Central Drive structures are not currently within the 100-year flood plain, it is unlikely that owners would possess flood insurance or have prepared adequate flood proofing measures. Consequently, potential flood damages could be even greater due to the lack of preparedness.

3. <u>Transect 2</u>
<u>1-2 Foot Range</u>

For the area near transect 2, an area encompassing a state beach, dunes would be overtopped by a 100-year coastal storm event. However, the hydraulic analysis revealed that wave runup would not govern the extent of flooding especially in the vicinity of Sage Lot Pond. A site investigation and review of the most recent USGS quadrangle map and aerial photographs has shown that the transect 2 area possesses a considerable amount of vegetation which will dissipate the wave energy. In addition, this heavily vegetated area is predominantly undeveloped land for approximately 2500 feet from the shoreline. Therefore, even though a 1-2 foot range in sea level rise will create elevated flooding levels, few if any structures would be affected. In addition, elevated flooding levels may cause erosion of an unimproved dirt road which gives access to the state beach.



100-YEAR COASTAL FLOOD LIMIT
CENTRAL DRIVE AND MONOMOSCOY ROAD

FIGURE 6

3-9 Foot Range

Since the area near transect 2 is predominantly a state beach and heavily vegetated, even at 3-9 foot range of sea level rise, few if any structures would be effected. However, at these flooding levels, one should consider the potential detrimental effects on vegetation. Moreover, at this range of sea level rise, the increased flooding may create enough erosion to undermine the unimproved dirt road used for access to the beach. Similar to transect 1, upper riverine areas will experience elevated flooding based on the stillwater elevations.

4. Transect 2 and 3
1-2 Foot Range

Between transect 2 and transect 3 the terrain is very consistent and, therefore, will experience similar wave effects. The area is predominantly a sandy beach with few man-made structures along the coast. Based on a recent site investigation, it appears that only a beach parking lot would be impacted by wave runup. Areas in the vicinity of Manitoba Road, Neshobe Road and Nehoiden Road will experience elevated levels of flooding for the 1-2 foot range of sea level rise. (Note: Portions of Manitoba Road are already within the 100 year flood zone.) Since this area is predominantly developed with residential dwellings, more structures will experience flood damages. In addition, similar to transect 2, as one moves farther inland from the coast, for instance riverine areas beyond Neshobe Road, 100-year stillwater levels will define the flood limits.

3-9 Foot Range

At 3-9 foot range in sea level rise, the entire area surrounding Neshobe Road will be inundated. Neshobe Road in particular will be completely inundated at 6 foot sea level rise. This flooding will result in a significant increase in flood damages to structures especially since residential structures within much of Neshobe Road and Topping Lift would not have been inundated under existing baseline 100-year coastal flood conditions.

5. <u>Transect 4</u>
<u>1-2 Foot Range</u>

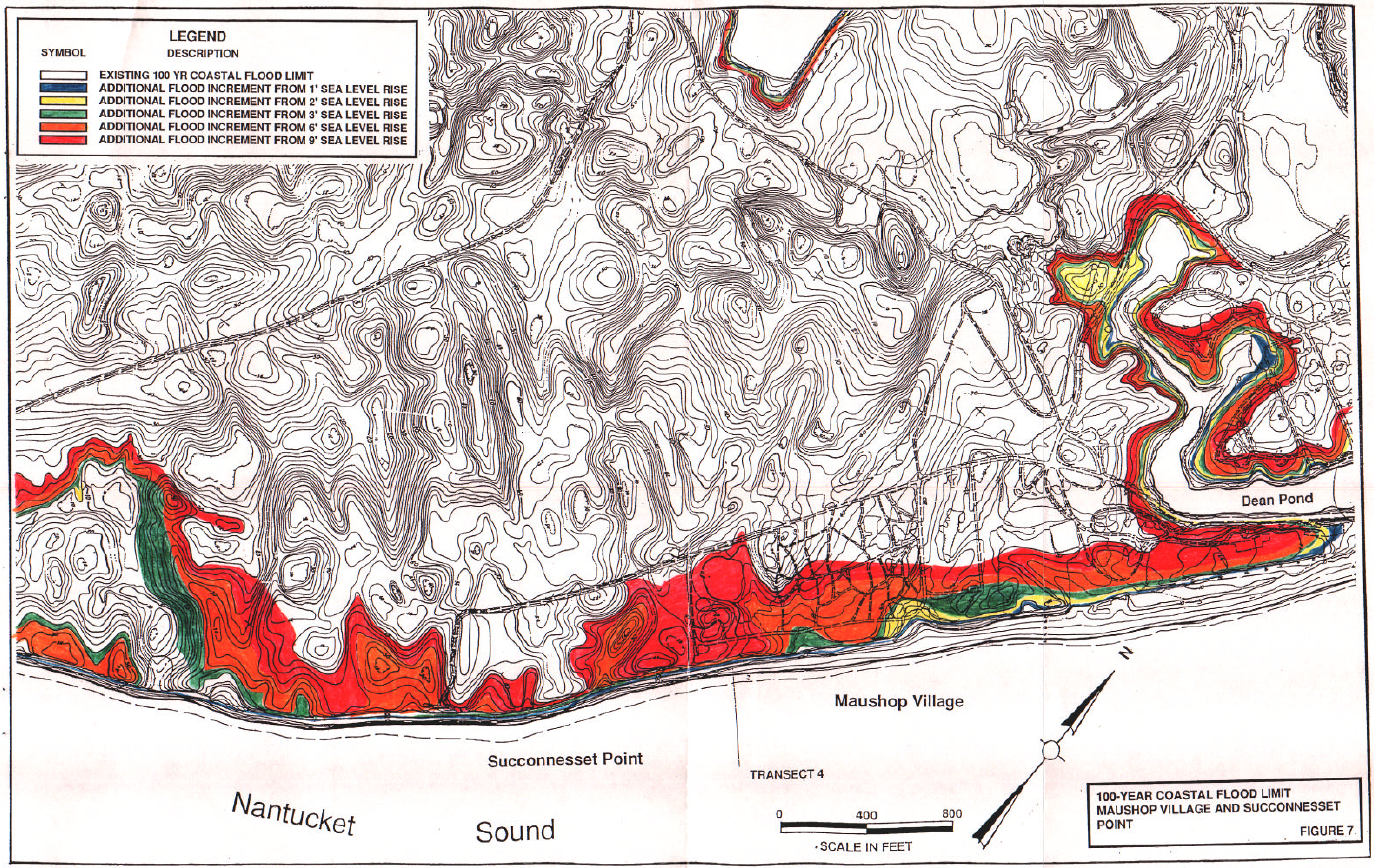
Transect 4 will be primarily influenced by wave runup effects because of its steep-sloped terrain. The transect is located near Maushop Village of the New Seabury development. For the most part, at the 1-2 foot range the cliffs are of a sufficient height (about 40 feet) near transect 4 that wave runup will not overtop the bluff. However, there are presently numerous small cottages (summer dwellings) located near the edge of the cliffs in the immediate vicinity of Maushop Village which would be impacted by the additional wave runup caused by the increased sea level rise. Under baseline 100-year coastal wave runup conditions, this area would not be inundated. At the 1-2 foot range, several houses along Cross Street in Maushop Village will be the primary structures impacted (See Figure 7). In addition to the increased flood limits, the increased wave runup will contribute to coastal erosion along the area between transect 4 and transect 5. However, the extent of erosion was not quantified as part of this study.

<u>3-9 Foot Range</u>

Because delineation of flood zone limits is governed by the contour elevations of the wave runup, sea level rise of 6 feet to 9 feet will have significant impact (See Figure 7). At a 9 foot sea level rise, a 100-year coastal storm will generate a runup sufficient to overtop the bluff face thereby inundating any structures on the top of the bluff. Residential structures within the Maushop Village housing development and Succonnesset Point will experience the greatest impact. In addition, with these levels of wave runup, erosion of the bluff will likely increase. However, as mentioned previously, the extent of erosion was not quantified as part this study.

6. <u>Transect 5</u>
<u>1-2 Foot Range</u>

The profile for transect 4 indicates that only about the first 100 feet from the shore will experience the effects of wave runup, however, because the slope and ground elevation



100-YEAR COASTAL FLOOD LIMIT MAUSHOP VILLAGE AND SUCCONNESSET POINT

FIGURE 7

varies as one moves down the coast towards transect 5, it appears that greater areas will be inundated. The steepness of the cliffs decreases significantly as one moves down the coast line towards transect 5. Since the slopes near transect 5 are at a lower elevation and descend into more level plateaus, this area will experience greater effects of wave runup due to sea level rise (See Figure 7). Nevertheless, one must continue to recognize that the wave runup effects will dissipate as one moves farther away from the bluff face. Moreover, specific damage to structures due to wave runup will be difficult to quantify.

At the more conservative 1-2 foot range of sea level rise, houses located in the Popponesset area particularly those structures located at the ends of streets such as: Starboard Lane, Overlook Knoll Road, Seaview Avenue, Bluff Avenue and Wilson Grove will experience increased flooding. Similar to transect 4, continuous wave attack at transect 5 will eventually undermine the slope. However, at transect 5 there is recently repaired or replaced stone revetment which will provide some measure of shoreline protection. But because only one side of the shore has rock protection, the slope will eventually be undermined via the unprotected side.

3-9 Foot Range

At the 3-9 foot range of sea level rise, additional structures in the Popponesset area will experience flood related damages. Residential structures adjacent to Popponesset Creek on Spoon Drift Way and Wading Place will also be inundated during the 3-9 foot range resulting in corresponding increases in flood damages to structures.

7. Transect 6

1-2 Foot Range

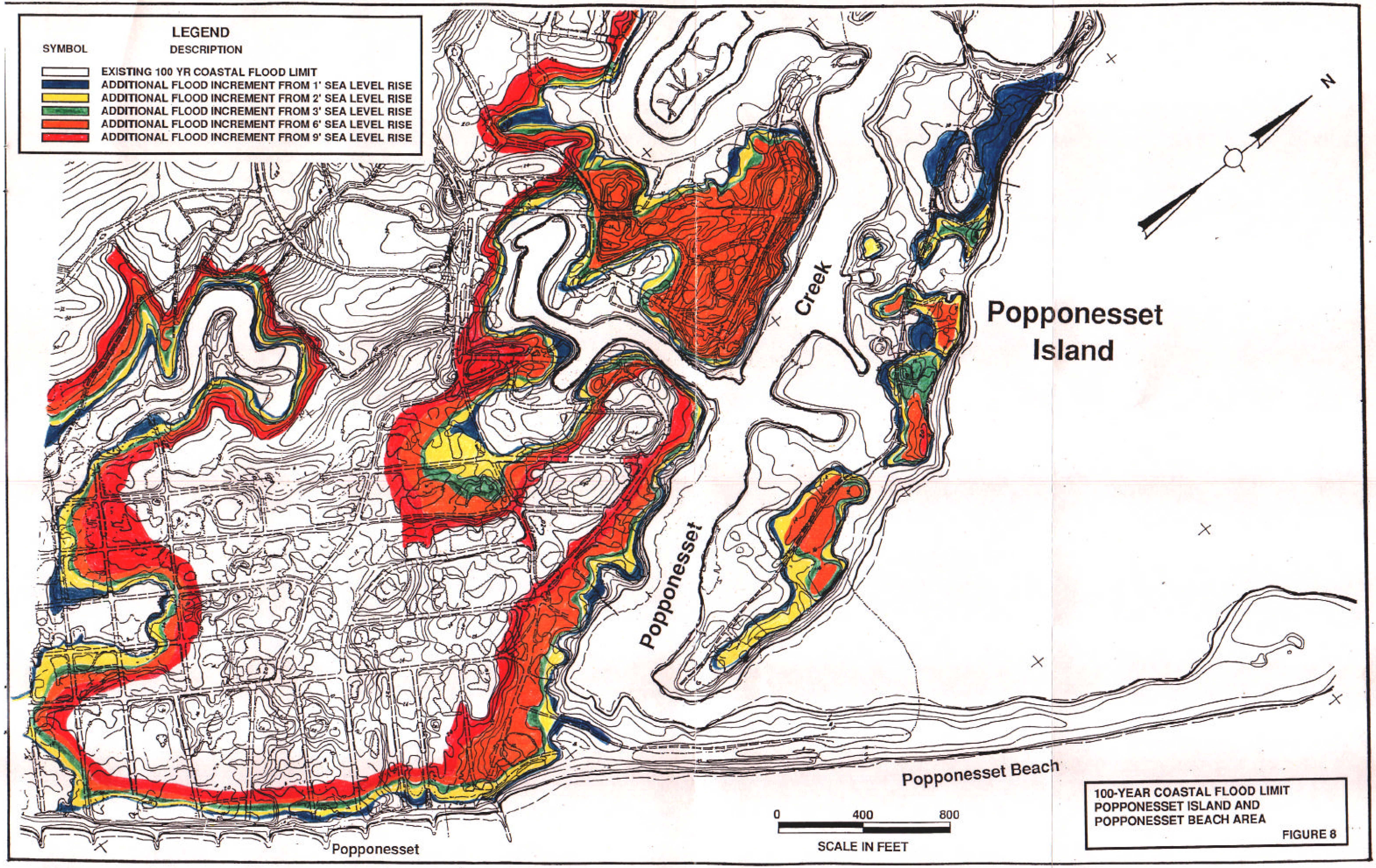
Both wave runup and wave height effects will play a role at transect 6. Transect 6 is located along Popponesset Beach. Based on computer output and map delineations, Popponesset Beach and Popponesset Island would experience significant flooding from the baseline 100-year coastal flood without sea level rise. At the 1-2 foot range of sea level rise, the Popponesset Island area will experience elevated flood levels in addition to increased flood zone limits (See Figure 8). The most evident result of the increased flooding will be a greater number of structures and properties impacted by flooding and for those structures affected, potentially higher monetary damages. A detailed survey of structures would provide more precise data on damages due to increased flooding.

3-9 Foot Range

As illustrated in Figure 8, at a 9 foot sea level rise, the Popponesset Island area will be completely inundated. The complete inundation of the island will have direct consequences to increase flood related damages. Since most areas would already be affected by the 1-2 foot range, the additional flood levels created by the 3-9 foot range will further increase potential flood damages.

8. Transect 7
1-2 Foot Range

Transect 7 is mostly governed by wave runup. Since transect 7, near Mashpee Neck is on the corporate limit with the Town of Barnstable, one would have to perform an updated wave height and wave runup analysis incorporating sea level rise effects and interpolate accordingly. Since this study does not interpolate between the two communities, the overall flooding impact is difficult to determine. However, the hydraulic analysis of Mashpee (without interpolation) at transect 7 revealed that at the 1-2 foot range of sea level rise, wave runup will not overtop the fronting barrier beach. The slope of the barrier beach will afford considerable protection from large ocean waves. In addition, similar to the other transects, for areas beyond the V zone, the 100-year coastal flood limits are defined by the 100-year stillwater elevations for the specific sea level rise increment.



100-YEAR COASTAL FLOOD LIMIT
POPPONESSET ISLAND AND
POPPONESSET BEACH AREA
FIGURE 8

3-9 Foot Range

At the 3-9 foot range of sea level rise, the fronting barrier beach may not afford adequate protection against large waves. Consequently, more structures and land will be subject to wave attack. Likewise, upper riverine areas will experience elevated flooding levels.

C. Salt Marshes

1. Salt Marsh Vegetation

Before summarizing the effects of sea level rise on salt marshes, a brief description of salt marsh zonation is necessary. Salt marshes are generally classified into two types based on the frequency of tidal flooding and vegetation type. The low marsh, or regularly flooded marsh, occurs roughly between the level of mean high water (MHW) and mean low water (MLW). In general, its elevational range is wider where the tidal range is greater (McKee and Patrick, 1988). The dominant vegetation in the low marsh is the tall form of salt marsh cordgrass (Spartina alterniflora). The high marsh, or irregularly flooded marsh, occurs between MHW and the level of the highest astronomic tides. The dominant vegetation types in the high marsh are salt meadow grass (Spartina patens), spike grass (Distichlis spicata), and black grass (Juncus gerardi).

2. Sea Level Rise Effects

There are three possible outcomes of sea level rise as identified by Orson et al. (1985; cited by Phillips, 1986):

1) marsh expansion when sedimentation exceeds submergence;

2) marsh maintenance if sedimentation balances submergence; and

3) marsh drowning when sediment supply and accretion is less than the rate of coastal submergence (a combination of sea level rise and land subsidence). Marsh drowning is associated with erosion of the seaward edge of the marsh.

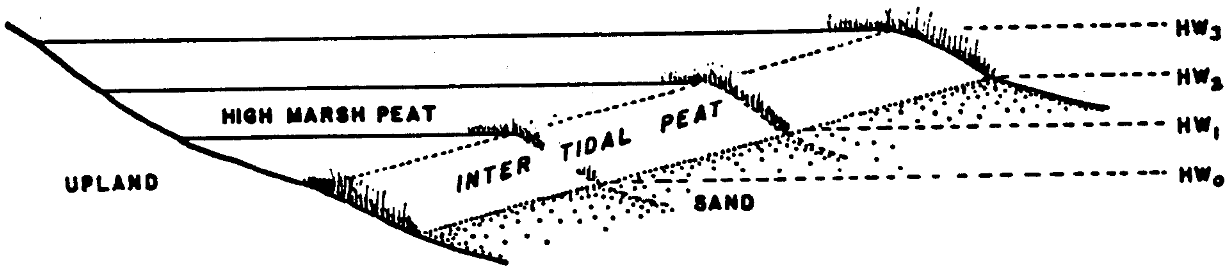
3. Marsh Expansion and Maintenance

A marsh can expand or maintain itself where the sediment supply is sufficient to keep pace with the rate of sea level rise. Nixon (1982), in "The Ecology of New England High Salt Marshes: A Community Profile," summarized the response of salt marshes to sea level rise. According to Nixon, the most recent, and generally accepted, view of how marshes adjust to sea level was described by Redfield (1972) in his classic study of Barnstable Marsh on Cape Cod. This synthesis combines the earlier theories of N.S. Shaler (1886) and B.F. Mudge (1862) on marsh development with new research and an understanding of the role of sea level rise. Nixon summarized Redfield's findings as follows: "With a rising sea level and a sufficient sediment supply...the intertidal S. alterniflora peat extended progressively out from the shore and at an upward slope over an aggrading sand and mud deposit. The high marsh peat then formed over the intertidal peat as a wedge which thinned as it expanded toward the upland and the seaward edge of the marsh." In other words, salt marshes adjust to sea level rise by expanding inland and waterward and increasing in elevation through accumulation of sediments and plant biomass. This process is illustrated in Figure 5.

4. Marsh Drowning

In the total absence of surface accretion, the quantity of high marsh would decrease and the low marsh would move up in elevation until high marsh disappeared and the upland slope eventually reached a near vertical level. A fringing salt marsh would develop along the shoreline based on the new tidal range. A rise in sea level would cause a corresponding increase in the elevation of MHW and the highest astronomic tides which delimit the major marsh boundaries. As MHW moved up in elevation, the low marsh/high marsh border would migrate across the high marsh until the high marsh drowned from too high a frequency of flooding. When the level of MHW exceeds the elevation of the highest existing area of high marsh, no high marsh would remain. While migrating up in elevation, the seaward limit of the low marsh would be exposed to

Model for Salt Marsh Development



Redfield's model for salt-marsh development over accumulating sediment on a sand flat and over the upland under the influence of rising sea level (Redfield 1972). HW refers to mean high water at various times during development.

From Nixon, 1982, "The Ecology of New England High Salt Marshes: A Community Profile.", Figure 1.

FIGURE 5

increased erosional forces preventing the low marsh from increasing in size laterally. Eventually, the low marsh would also be overtaken by the frequency of flooding until only open water remained. When the level of mean low water (MLW) exceeds the elevation of the low marsh, low marsh would no longer remain.

There are other factors, interrelated with sediment availability, which affect the ability of a salt marsh to keep pace with sea level rise: 1) erosion at the seaward edge; 2) slope of the adjacent upland; 3) coastal engineering structures which may physically prevent landward saltmarsh migration; 4) armoring of coastal banks/bluffs may eliminate sediment availability which may impact the ability of a saltmarsh to keep pace with sea level rise; and 5) the rate of sea level rise. The quantity of channels, ditches, and pannes on a marsh also influences the ability of the marsh to keep pace with sea level rise (Phillips, 1986).

Erosion of the seaward edge limits the ability of the marsh to grow outward. The amount of erosion on the seaward edge of the marsh is difficult to determine but is dependent on the amount of sea level rise and the rate at which new sediment is supplied. If the rate of sea level rise exceeds the rate of accretion, the seaward edge of the marsh will erode. That material eroded from the edge will be spread across the marsh surface to increase its elevation (Reed, 1988). Bruun (1962) developed a method now known as the Bruun Rule to determine the erosion rate due to sea level rise. As summarized by Phillips (1986), "The Brunn Rule holds that, for a shoreline in longshore equilibrium, a given rate of sea level rise will result in shoreline erosion sufficient to deposit sediment in the nearshore zone to a depth equal to sea level rise." (The nearshore zone is the zone along the shore affected by waves.) The quantity of material eroded from marsh edges would have to be sufficient to cover the nearshore area, which has a width that expands with erosion, minus sediment input from outside of the marsh, for the seaward edge of the marsh to maintain or expand its lateral extent before marsh accretion can occur.

A given erosion rate under each of the sea level rise scenarios would require an increasingly greater accretion rate to maintain the marsh area where the slope of the adjacent upland is greater (Phillips, 1986). Where seawalls or bulkheads are constructed along the shoreline, the slope is considered to be very steep. Assuming that the sediment supply is not sufficient to supply the marsh surface and the nearshore zone at a rate that will allow the marsh to keep pace with sea level rise, erosion of the seaward edge of the marsh will occur. With an erosion rate caused by a constant sea level rise, the accretion rate would have to be higher to maintain the existing marsh area where the upland slope is greater (Phillips, 1986). However, the accretion rate is dependent on marsh flooding. In general, those areas that experience flooding more frequently have a greater ability to accrete. To keep pace with the erosion rate, the accretion rate would have to exceed the rate of sea level rise. While this can occur (Nixon, 1980), it is not likely to maintain the marsh over the long term.

Expansion of salt marsh in Mashpee would most likely occur in areas now dominated by fresh water-brackish marsh and shrub/forested swamp along the salt marsh/upland edge since these areas often gradually transition into salt marsh in contrast to steeper upland slopes. This would simply be a response to the increase in flooding and salinity levels. It would result in a reduction in the amount of tidal fresh water and brackish marsh. No accretion would be necessary to maintain these areas as wetland until the level of MHW exceeded the level of these marshes.

5. Effects on the Marshes of the Town of Mashpee

Assuming no sediment is added, assumptions can be made about the fate of salt marshes in Mashpee. The difference between the mean tide range and the spring tide range at

Poponesset Bay in Mashpee is 0.5 ft. (NOS, 1992). Using this as a rough estimate of the vertical range of high marsh (accounting for the high marsh range to the highest astronomic tide level), all high marsh would be eliminated with a 0.5 ft. rise in sea level. Assuming that the low marsh extends from MLW to MHW (mean tide range) a vertical extent of 2.3 ft., all low marsh within the footprint of existing salt marsh would not be eliminated until sea level rise exceeded 2.8 ft. With 3-9 feet of sea level rise, only open water and a thin salt marsh fringe would be present. However, as previously discussed, salt marshes can adjust to sea level rise with sediment input, if sufficient landward area is available to allow the marsh to migrate. However, armoring, e.g. seawalls, revetments, etc. or dikes may prevent saltmarsh migration resulting in considerable loss of marsh.

Since the ability of a marsh to keep pace with sea level rise is dependent on sediment supply, site-specific analyses of the watershed and coastal sediment inputs would be required to determine the reaction of the marshes in Mashpee to sea level rise. Modification of coastal environments and upland sand sources which the decrease the amount of sediment available for accretion may limit the ability of the marsh to keep pace with sea level rise. Without site-specific analysis, it is expected that the elevation of the marsh surface could keep pace with the historic rate of sea level rise (2.9 mm/yr; 0.9ft/100yr). Generally salt marshes have been found to keep pace with sea level rise of this magnitude (Nixon, 1982; Reed, 1988). It is not possible to estimate the effects of sea level rise of 2 or 3 feet under the level of effort for this study, although in general the higher the rate of sea level rise the greater the likelihood of marsh drowning.

Under the 6 ft/100 yr (18 mm/yr) and 9 ft/100 yr (27 mm/year) sea level rise scenarios, major reductions in the area of salt marsh would most likely occur since the quantity of sediment input would have to be very high. However, if the sediment supply were sufficient, the marsh could probably adjust to even these extreme rates of sea level rise (Nixon, 1982).

6. Effects at the Study Transects.

Assumptions can be made about the effect of sea level rise on the salt marshes of Mashpee at the study transects. Transects 1, 2, and 3 for this study pass through salt marshes. Transect 1 passes through the southernmost tip of Seconsett Island. The salt marsh here appears to be highly suceptible to erosion with sea level rise. Phillips (1986) found that pennisular points such as this, in Delaware, experienced rapid truncation with sea level rise. The portion of Transect 1 north of Hamlin Pond crosses a fringing salt marsh adjacent to a fairly steep upland slope. Loss of aerial extent would be more likely here if extreme sea level rise causes erosion of the seaward edge and the sediment supply is not sufficient to maintain the existing area at an increasing elevation. Those portions of Transects 2 and 3 that pass through salt marshes are located in areas with shallow slopes; these areas would be most capable of adjusting to sea level rise without losing salt marsh area.

D. Groundwater

Although this study did not analyze the specific effects that rising sea level may have on groundwater supplies, scientific literature has suggested that even relatively small increases in sea level could cause significant impacts. The saltwater wedge through estuaries and tidal rivers could advance as a result of sea level rise, causing saltwater intrusion of coastal aquifers. Some researchers have indicated that a sea level rise of 10 centimeters (3.9 inches) could cause a landward shift of the saltwater wedge by as much as 1 kilometer (0.62 miles) (NRC, 1987). Consequently, groundwater supplies could be threatened by saltwater intrusion by only small increases in sea level. Although this study did not quantify the salinity intrusion, it is apparent that even at the historic sea level rise rate of about 1 foot/100 years, the increased salinity levels could cause dramatic impacts to groundwater supplies.

VI. Conclusions

Based on the previous sections, several conclusions can be drawn as to the associated impacts that increased sea level rise could have on a coastal community such as Mashpee, Massachusetts.

1. Sea level rise predictions during the next 30-40 years are generally consistent with historic rates of sea level rise.

This study determined that for planning purposes, it would be appropriate to focus on the 1-2 foot range of sea level rise for practicality when dealing with the short term (30-40 years). Likewise, although sea level rise is highly variable during the long term (100 years), this study found that using the 3-9 foot range of sea level rise would provide an adequate model of the more severe impacts.

Organizations charged with managing the coastal zone, should be aware of the inherent uncertainty associated with selecting any of the various sea level rise predictions to use in determining actions in response to sea level increases. To overcome this uncertainty, several sea level rise projections were compared over a 100 year period. It was determined that short term (30-40 years) projections are fairly consistent with the historic rate. However after about 40 years, there is considerable disparity between sea level rise projections such that sea level rise may range from a few feet to 9 feet or greater.

a) Different magnitudes of sea level rise will affect flooding.

As this case study of Mashpee has shown, variations of sea level rise will result in different magnitudes of flooding impacts and environmental impacts. For instance, during the short term, for a 1-2 foot range of sea level rise, most low-lying, flat terrain areas will experience greater levels of flooding and wider limits of flooding. At this same range, most steep areas which are governed primarily by wave runup , will be safe from overtopping.

However, in the long term (100 years), the impacts of sea level rise on flooding will dramatically increase if sea level rise reaches 6-9 foot increases. In this range, many flat areas within Mashpee, which would normally be free from flooding would be completely inundated. In addition, if sea level has increased by 6-9 feet, steep areas such as those located near Popponesset and Maushop Village in Mashpee will experience overtopping and flooding which would not have affected the areas as significantly under the 1-2 foot range.

b) Different magnitudes of sea level rise will affect salt marsh development.

In addition to variations in flooding impacts, salt marsh development will have a strong correlation to magnitude of sea level. Although, salt marsh development is extremely site specific and dependent on sediment supply, salt marshes should be able to maintain their current elevations under historic trends during the short term. During the long term, a higher rate of sea level rise is predicted. Generally, under higher rates of sea level rise, there is a greater likelihood that marsh drowning would occur assuming the sediment supply was deficient. For instance, sediment supply could be deficient as a result of armoring of coastal banks which are the primary source of terragenous material.

2. Determining sea level rise impacts is an extremely site specific analysis.

Although impacts from sea level rise are extremely site specific, this case study of Mashpee provides a useful tool for regulatory or planning agencies in that it identifies impacts with respect to common types of coastal features. Because the community of Mashpee possesses a variety of natural resources as well as developmental characteristics, it provides a good example of the range of impacts that could potentially occur. This study has revealed that sea level rise effects vary considerably according to such factors as: a) slope; b) coastline and topography; and c) land use, i.e. undeveloped, developed, etc.

a) The 100-year coastal storm will cause different effects based upon slope variations.

In the short term, mostly flat beach areas will be affected by coastal dune erosion and generally wave height analysis will govern, whereas extremely steep cliffs will be controlled predominantly by wave runup effects. Since both situations would cause a different type and magnitude of impact, planning or regulatory agencies would have to devise different strategies for future management. For instance, an area that experiences greater wave runup might place greater emphasis on coastal erosion, whereas an area dominated mostly by flat areas might be more concerned with flooding and consider relocation of structures or flood proofing. Since higher sea level rise projections are not expected until the long term, in general, significant wave runup would not occur until then. Therefore, steep areas will not experience flooding until the long term, when the higher sea level rise projections are morely likely to occur.

b) The type of coastline and topography will affect both flooding and environmental impacts.

This study found that at 1-2 foot range of sea level rise, wave runup did not appreciably affect a heavily vegetated area because the vegetation dissipated the wave energy. However, in adjacent areas of beach, it was necessary to be concerned with coastal dune erosion. Other areas, because of their high elevations were not inundated even during a 9 foot sea level rise scenario. Nevertheless, sea level rise during the long term may reach levels sufficient to cause overtopping and additional coastal erosion.

c) The type of land use plays a critical role in determining flood impacts.

In Mashpee, for instance, residential and business areas will probably experience greater flood related damages due to sea level rise than say a beach or other undeveloped area. Without a more detailed site specific economic analysis, it is reasonable to conclude that in general residential and business areas with their greater number of structures will tend to have more flood induced damages. For example, commercial structures that contain stored materials, warehouse goods, equipment and machinery may be damaged by flood waters in addition to any flood related structural damage. A beach will perhaps have only a few structures that would be impacted. However during severe flooding there could be significant beach erosion requiring future beach nourishment.

3. Sea level rise will have a significant effect on coastal flooding.

Based on the analysis of Mashpee, this study has determined that sea level rise will have a significant effect on coastal flooding. Although, the amount of flooding impact will vary according to the level of rise, this study has found that flooding will increase even based on historic trends. It is estimated that over the next 30-40 years, sea level rise will vary from about 0.3-1.0 feet . This level of rise may seem minimal, however, it could create significant flooding impacts to existing low lying areas. In the 100 year time frame, sea level rise will further contribute to significant flooding such that many areas not prone to flooding at present will be inundated. In the most extreme cases of sea level rise , i.e. 9 foot or greater, both flat terrain and steep cliff areas will be inundated.

4. Sea level rise will affect the rate of erosion of land in the coastal zone.

Although, this study did not quantify the extent of erosion, increased erosion is expected for unprotected areas subject to continued wave attack.

5. Sea level rise may increase saltwater intrusion of coastal aquifers causing contamination of groundwater supplies.

VII. Recommendations

Based on the conclusions presented in the previous section, the study reviewed how responsible organizations such as the Massachusetts Coastal Zone Management (MCZM) can address the problem of managing sea level rise. This study has focused on determining the potential impacts for several scenarios of sea level increase ranging from 1-9 feet. The report discusses a point of deviation between the various sea level rise projections and the historic rate of rise. Figure 2 illustrates the small differences between various sea level rise predictions over the next 40 years. Beyond this point there is a wide variation in predicted sea level rise. In order to develop a plan of action to address sea level rise, it is necessary to differentiate between short term and long term goals and objectives. Since there is uniformity between predictions in the next 30 to 40 years and these predictions are consistent with the historic rate of rise, it is logical to focus the Commonwealth's energies and resources to deal with the problems in this time frame. It is also important to understand the potential long term implications of more severe sea level rise and to closely monitor and adjust strategies to address these more serious impacts.

The discussion of the potential flooding impacts was presented whereby these impacts were divided into two major ranges: 1) 1-2 foot range and; 2) 3-9 foot range. The 1-2 foot range represented the range of sea level rise more consistent with historic trends, whereas the 3-9 foot range represented more drastic predictions. Although, both ranges of projections are possible and provide useful planning information, this report recommends that resource and regulatory agencies focus on the 1-2 foot range analysis, more representative of the potential short term impacts, in developing planning policy. Reliance on a predictive model more consistent with historic trends is more practical and defendable because there is data to support the trend. Nevertheless, planning and regulatory agencies should be alert to any changes in sea level rise projections and aware of the potential for significant impacts. It is recommended that agencies consider the following issues in evaluating sea level rise management strategies:

1) Development of a comprehensive resource inventory to assist in making informed decisions.

As mentioned previously, future sea level rise will cause complex results requiring careful planning and informed decision-making. In order to facilitate this process, critical information must be gathered and a comprehensive resource inventory developed. Many communities and state agencies within the Commonwealth of Massachusetts may already possess or are in the process of developing a great deal of the information needed for a resource inventory. The resource inventory should contain information such as types of natural resources, land use information, population as well as building information (See Figure 9). A successful resource inventory will enable the planner to evaluate the effects of sea level rise on a particular resource for its life span.

LANDUSE

- Commercial Development
- Industrial Development
- Residential Development
- Agricultural Development
- Recreational Development

INFRASTRUCTURE

- Roads
- Sewers and Drains
- Underground Utilities and Transmission Lines
- Bridges and Culverts
- Wastewater Treatment Plants
- Public and Private Wells
- Landfills

POPULATION

- Census Information
- Number and Type of Residents

NATURAL RESOURCES

- Coastal and Freshwater Wetlands
- Groundwater
- Aquifers
- Beaches and Dunes
- Channels and Harbors
- Rivers

COASTAL STRUCTURES

- Breakwaters and Jetties
- Boat Ramps, Docks, Piers

RESOURCE INVENTORY

FIGURE 9

Once information is collected, it must be gathered and organized in order to be useful for analysis. Creating a database will be an appropriate means to achieve this goal. Furthermore, the use of a geographic information system (GIS) may be a means of evaluating site specific impacts to a particular resource. Since the Commonwealth of Massachusetts has a well established GIS with a vast amount of data already developed, creation of a comprehensive resource inventory may not require a considerable amount of effort. GIS will facilitate the process of spatial analysis, enabling the planner to compare the appropriate resource database information with the flood impacted areas. In addition, GIS could also assist in evaluation of structural and nonstructural alternatives.

2) Because the magnitude of change from sea level rise is dependent on particular circumstances it requires careful consideration of many interrelated factors.

Resource and regulatory agencies must consider particular circumstances such as: the type of terrain, existence of particular structures, land use, population density, etc. The study identifies areas governed by wave runup which may result in increased erosion of steep cliffs. These areas will be impacted differently than other areas where wave height is a governing factor. Therefore, in order to develop an appropriate plan of action, one must weigh the alternatives carefully, for example whether to build or relocate in the event of a significant storm with sea level rise.

3) Determine the effects on coastal erosion, groundwater and wetlands.

In addition to determining potential flooding impacts due to sea level rise, an appropriate plan of action should consider other physical effects such as coastal erosion and groundwater impacts as well as potential loss of wetlands. In the short term, since wave runup is not as critical a factor, coastal erosion may not play as great a role, however over the long term, continual wave action may cause additional coastal erosion. In addition, the elevations of the coastal marshes should keep pace if sea level rise remains constant with the historical rate. Higher rates of rise could result in drowning of all existing low marshes and the loss of a significant portion of the high marshes. Therefore in order to develop policy for assessing the potential loss of wetlands, agencies should perform more site specific analyses. Likewise, a more detailed analysis of groundwater effects must be performed which should include monitoring.

4) Continue to reevaluate different predictive models and monitor trends in sea level rise.

Earlier sections discussed the various complex factors which contribute to global and local sea level rise and the inherent uncertainty associated with predictive models. Keeping this underlying uncertainty in mind, various incremental changes in sea level were selected as opposed to employing any particular projection. Using this approach, wave effects were analyzed and maps were created delineating areas of potential flooding impact. Continued monitoring of sea level rise and awareness of the scientific community projections is required to evaluate and adjust strategies.

5) Examine social, economic, and political factors influencing planning policy.

The development of a proper response to sea level rise requires an organization to examine the social, economic and political concerns in addition to the physical effects.

6) A site specific analysis is required. This investigation of Mashpee provides only a case model which describes some of the analysis one should consider.

This study also demonstrates that a proper response will require a site specific analysis. For instance, in the case of the residential dwellings near Maushop Village, one must perform some type of cost benefit analysis within the selected time frame to determine the economic feasibility of providing coastal shoreline protection versus either allowing the bank to erode or retreating. For instance, in the Maushop Village area, it may be determined that the value of the property and extent of erosion may justify providing the type of protection required. Alternatively, an analysis may determine that relocation is a better solution than providing protection.

7) Because sea level rise has many resultant effects, it is critical that policy makers make informed decisions.

In all cases, there are complex decisions to be made by individuals or organizations responsible for the management of financial resources as well as natural resources. Therefore, it is critical that local community officials, planners as well as state regulators and legislators are aware of the effects of sea level rise and have at least a cursory understanding of the coastal processes involved and the potential economic consequences.

By implementing the plan of developing a comprehensive resource inventory as recommended in this report and by monitoring the actual and forecasted sea level rise, state and local governments will be able to establish short and long term planning strategies to account for the impacts of sea level rise. Policy makers may utilize the tools of regulatory or legislative action to formulate strategies for reducing or mitigating the effects of sea level rise in a community or state. Their approach may include: requiring permits for coastal development; regulation through local zoning ordinances; purchasing of private land, etc. In the interim, actual sea level rise should continue to be monitored and the public should be informed of potential future impacts.

Sea Level Rise Impact Investigation
Mashpee, Massachusetts

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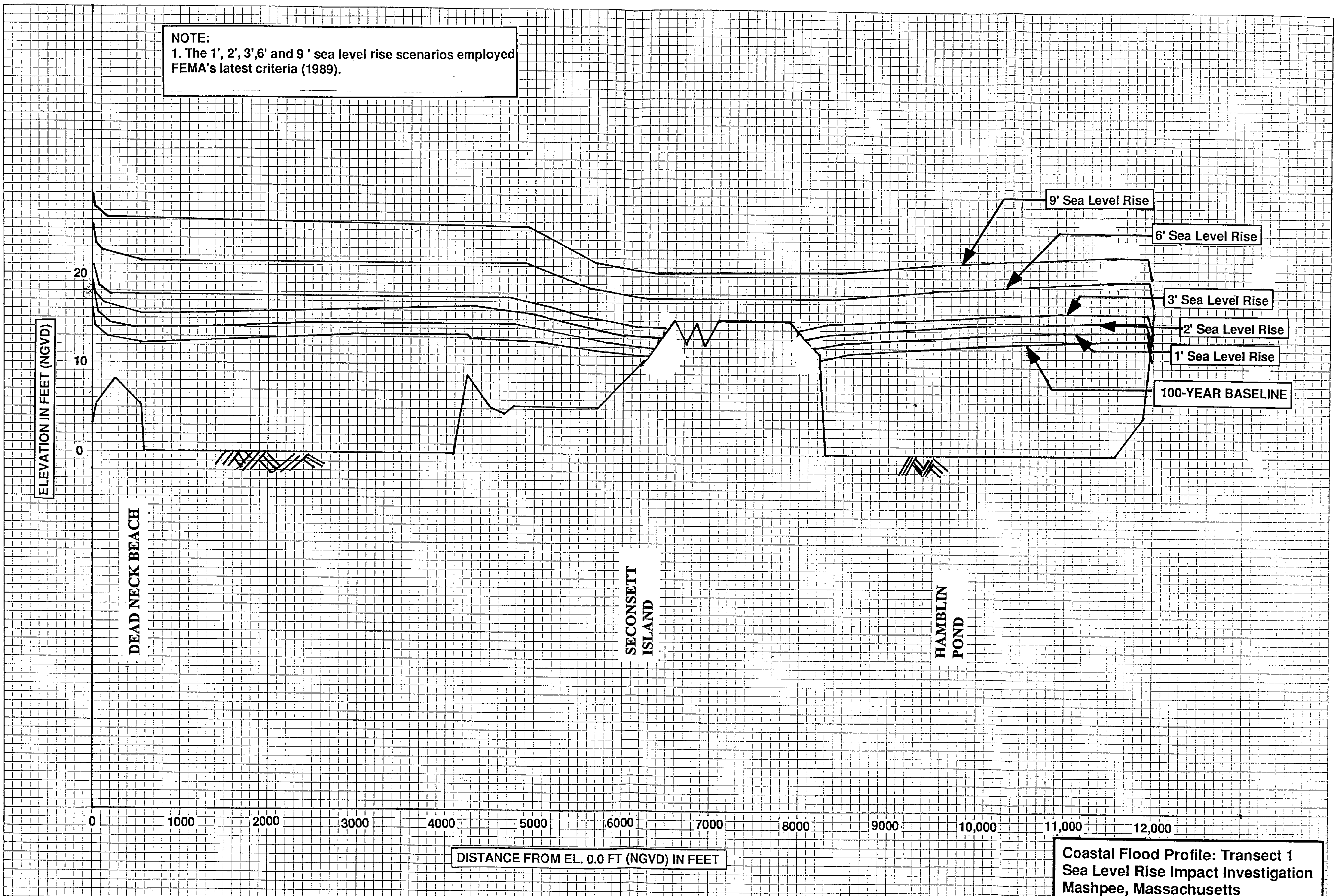
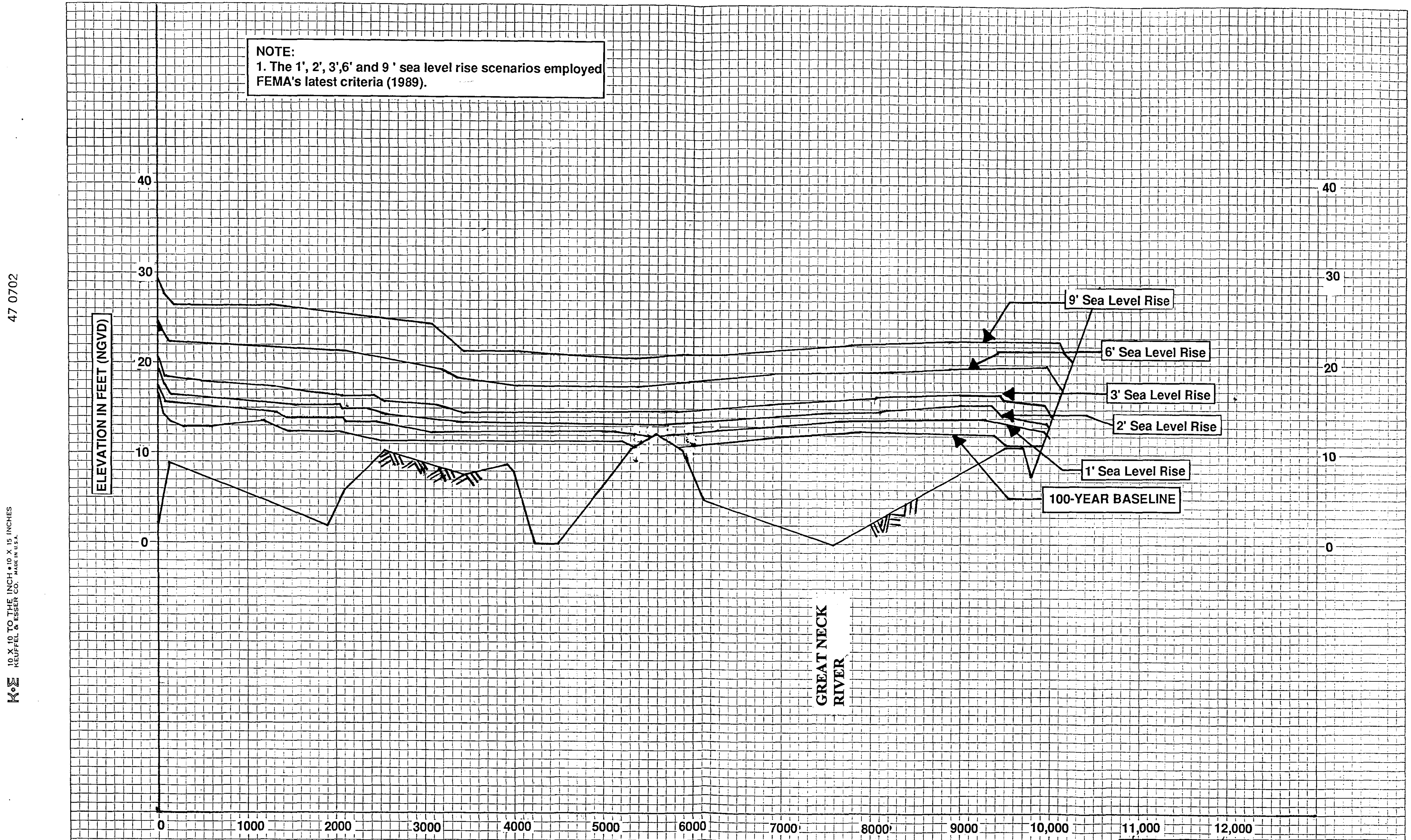
APPENDIX A
TRANSECT PROFILES



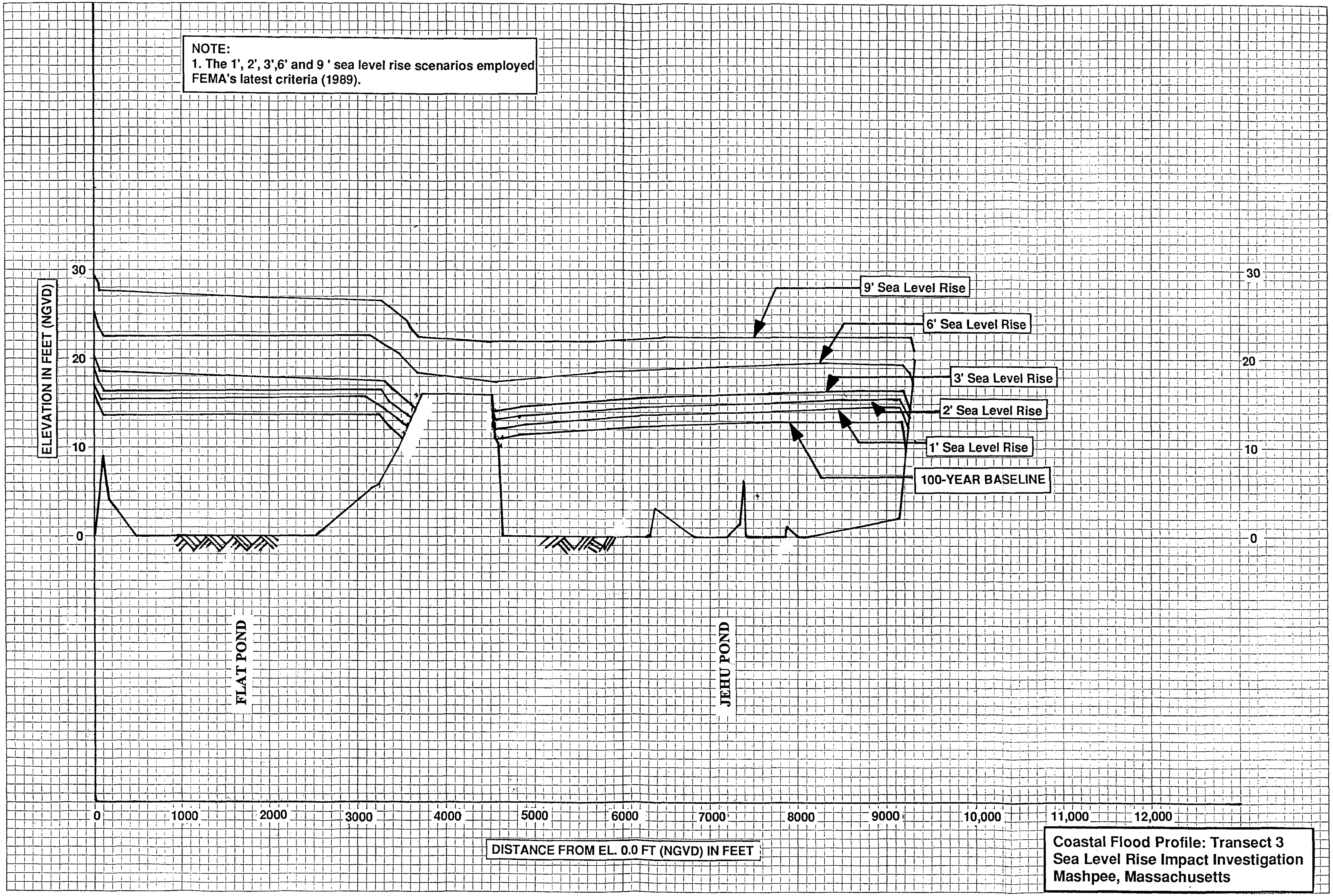
Coastal Flood Profile: Transect 1
Sea Level Rise Impact Investigation
Mashpee, Massachusetts

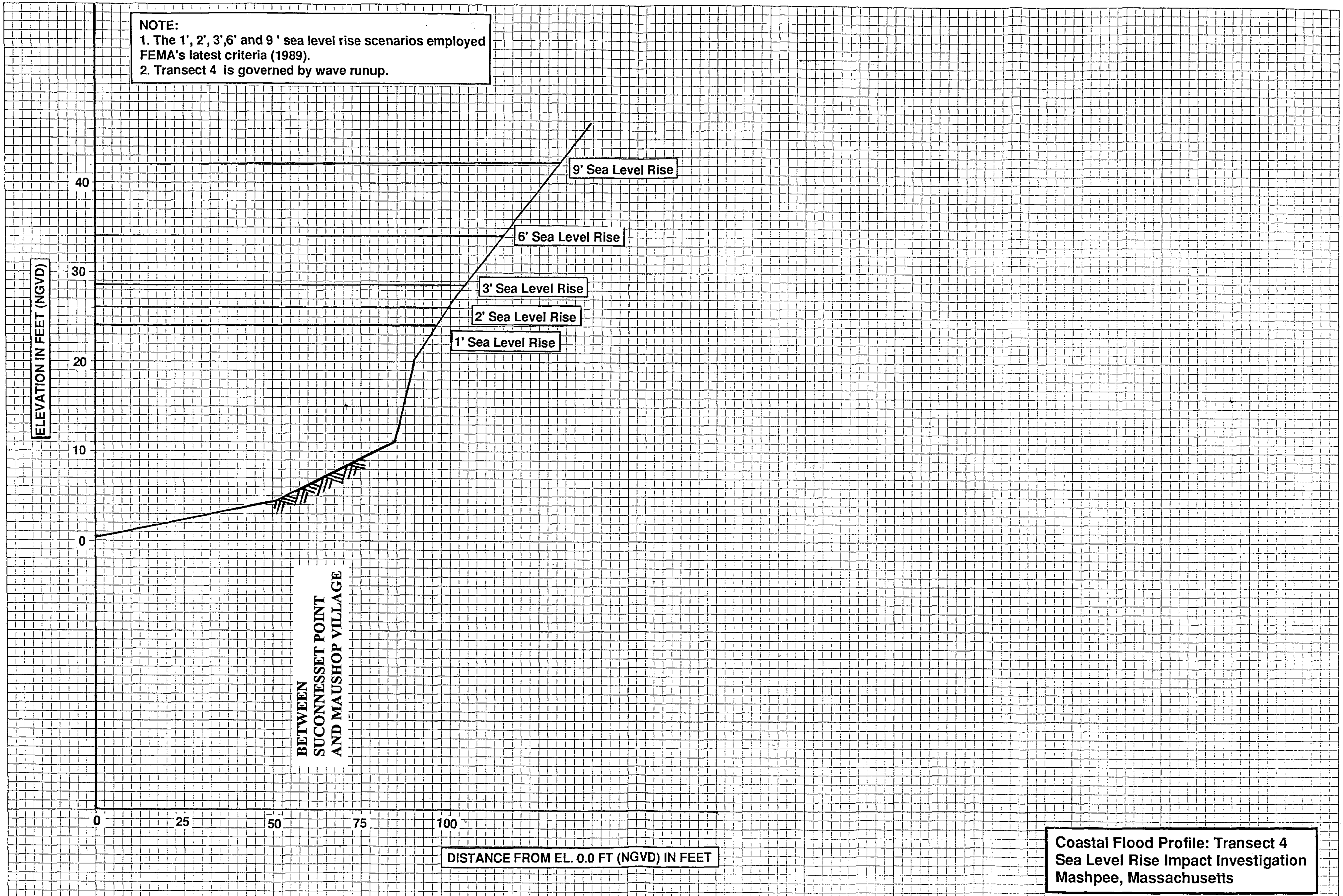
47 0702

K+E 10 X 10 TO THE INCH • 10 X 15 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

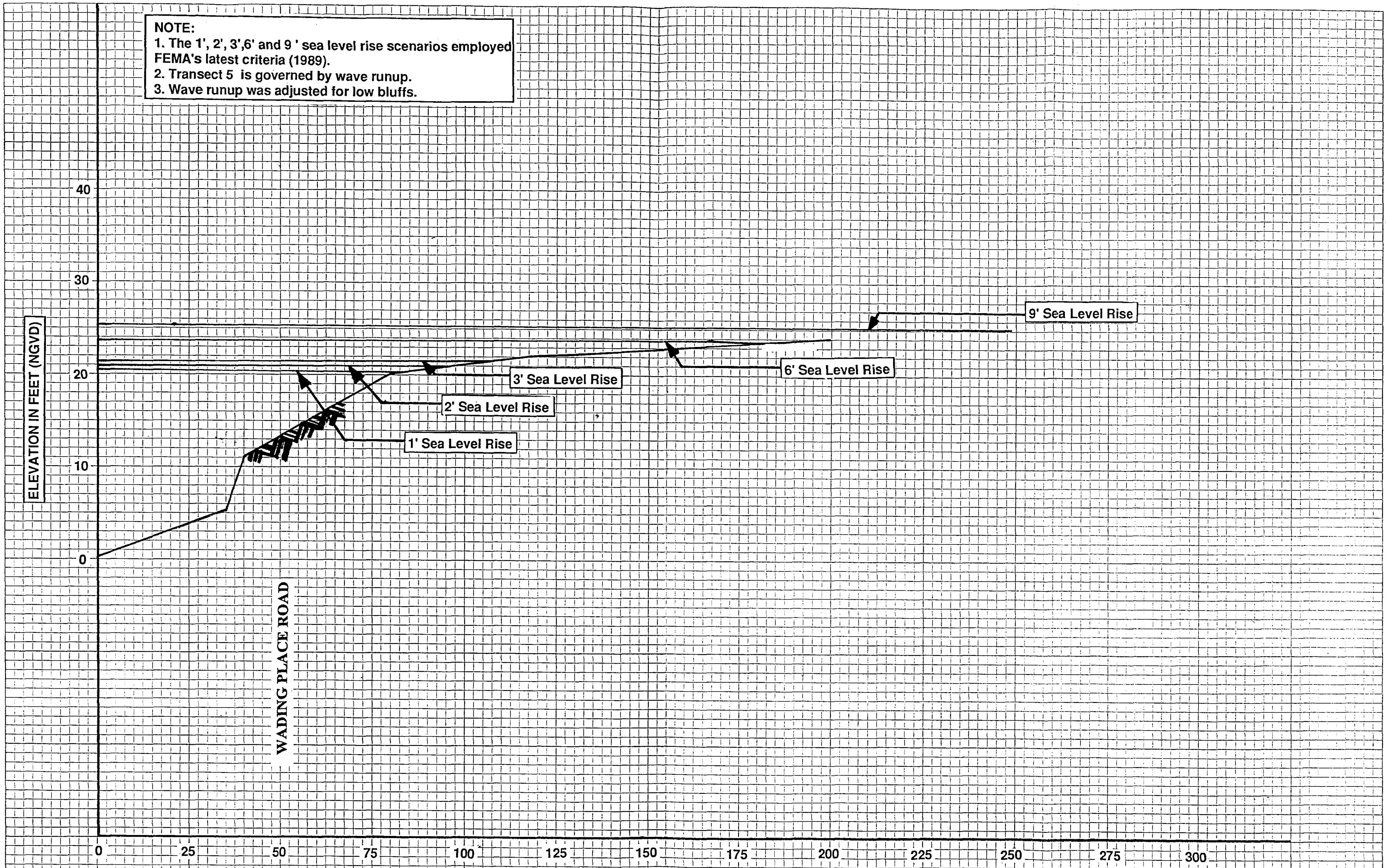


Coastal Flood Profile: Transect 2
Sea Level Rise Impact Investigation
Mashpee, Massachusetts


NOTE:
1. The 1', 2', 3',6' and 9 ' sea level rise scenarios employed FEMA's latest criteria (1989).
ELEVATION IN FEET (NGVD)
30
20
10
0
9' Sea Level Rise
6' Sea Level Rise
3' Sea Level Rise
2' Sea Level Rise
1' Sea Level Rise
100-YEAR BASELINE
FLAT POND
JEHU POND
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
DISTANCE FROM EL. 0.0 FT (NGVD) IN FEET
Coastal Flood Profile: Transect 3
Sea Level Rise Impact Investigation
Mashpee, Massachusetts



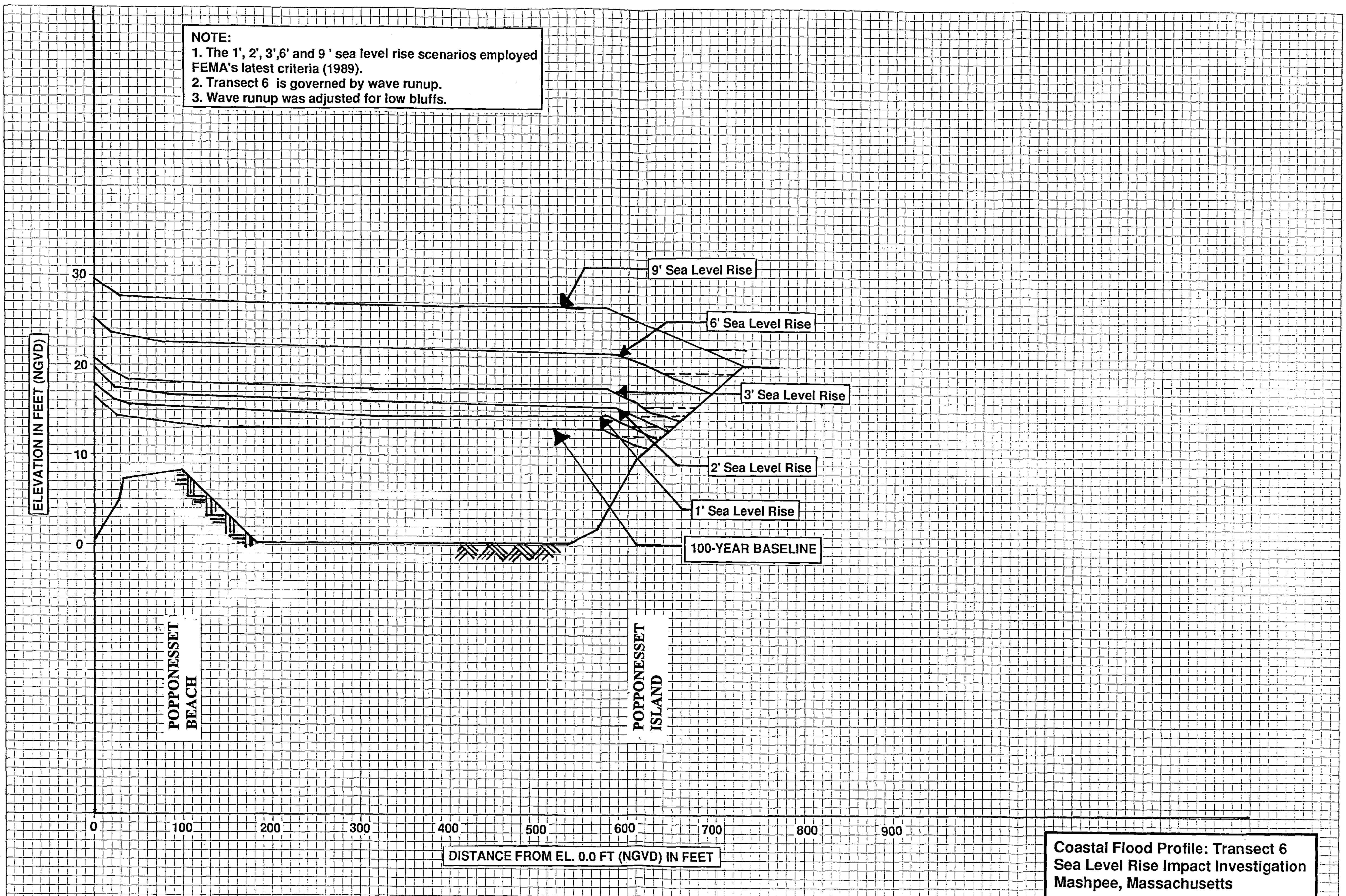
Coastal Flood Profile: Transect 4
Sea Level Rise Impact Investigation
Mashpee, Massachusetts



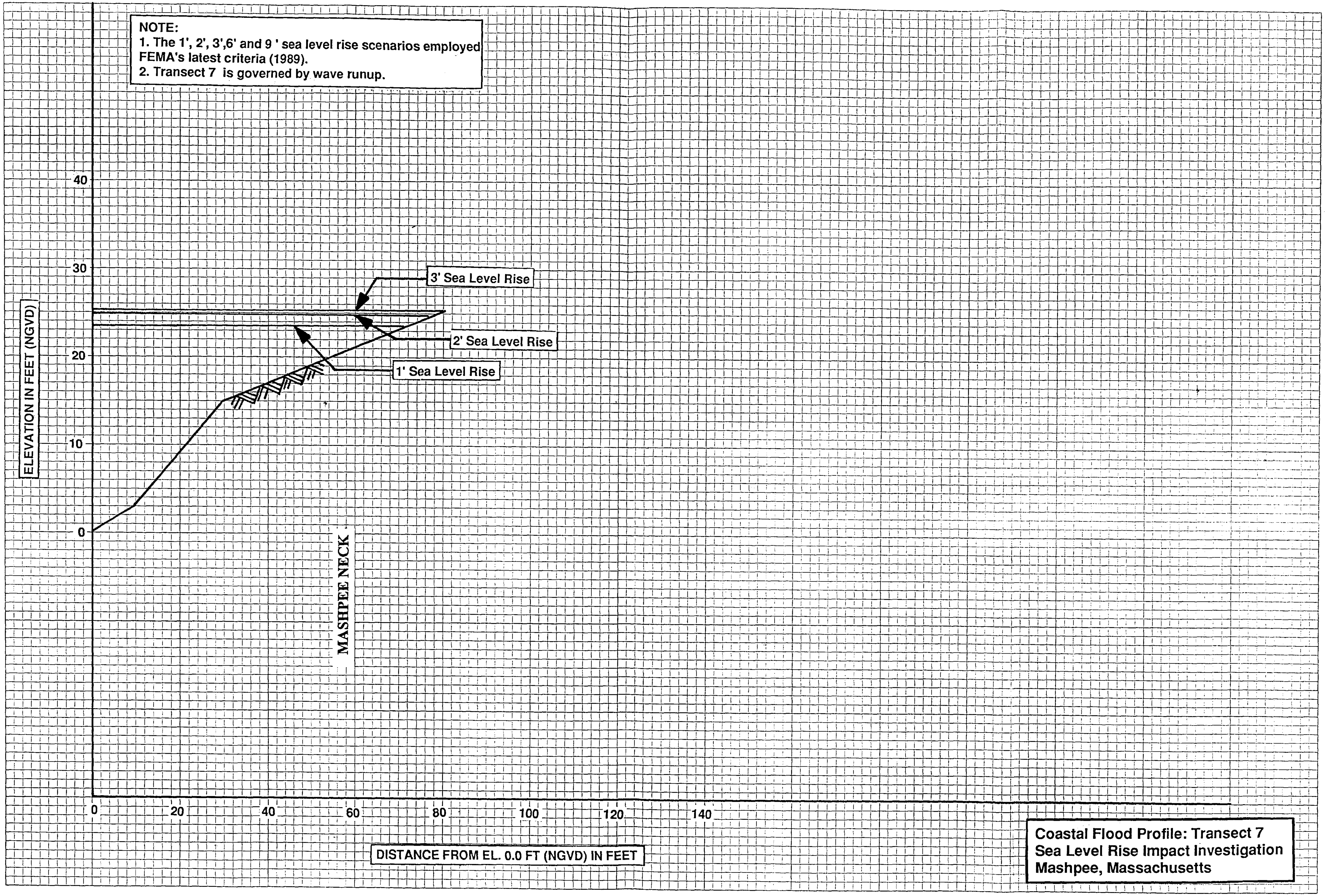
Coastal Flood Profile: Transect 5
Sea Level Rise Impact Investigation
Mashpee, Massachusetts

47 0702

K&E 10 X 10 TO THE INCH • 10 X 15 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.



Coastal Flood Profile: Transect 6
Sea Level Rise Impact Investigation
Mashpee, Massachusetts



NOTE:
1. The 1', 2', 3',6' and 9 ' sea level rise scenarios employed FEMA's latest criteria (1989).
2. Transect 7 is governed by wave runup.
3' Sea Level Rise
2' Sea Level Rise
1' Sea Level Rise
ELEVATION IN FEET (NGVD)
0
10
20
30
40
MASHPEE NECK
0
20
40
60
80
100
120
140
DISTANCE FROM EL. 0.0 FT (NGVD) IN FEET
Coastal Flood Profile: Transect 7
Sea Level Rise Impact Investigation
Mashpee, Massachusetts

APPENDIX B
HYDRAULIC ANALYSIS

IV. Hydraulic Analysis

a. General. Two types of wave processes govern hydraulic analysis of coastal flooding for this investigation. First, a wave height analysis was performed to determine wave heights and corresponding wave crest elevations for areas inundated by tidal flooding. Secondly, a wave runup analysis was performed to determine the height and extent of runup beyond the limit of tidal inundation. The results of these analyses were combined into a wave envelope, which was constructed by extending the maximum wave runup elevation seaward to its intersection with the wave crest profile. Methodology is described in detail in "Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping," Third Draft, Federal Emergency Management Agency (FEMA), July 1989.

Wave height methodology is based on procedures originally developed by the National Academy of Sciences (NAS) and described in their 1977 report entitled "Methodology for Calculating Wave Action Effects Associated with Storm Surges." Three major concepts form the basis of the NAS methodology. First, a storm surge on the open coast is accompanied by waves and the maximum height of these waves at any point is directly related to water depth. Secondly, natural and man-made obstructions will dissipate energy; thereby, diminishing breaking wave height. Thirdly, throughout unimpeded reaches between obstructions new wave generation can result from wind action which adds energy; increased wave height being related to distance and mean depth over the unimpeded reach. Wave height analysis was conducted using FEMA computer program "Wave Height Computations for Flood Insurance Studies," Version 3.0, September 1988.

Stone and Webster Engineering Corporation developed the procedures for wave runup analysis in their "Manual for Wave Runup Analysis, Coastal Flood Insurance Studies", November 1981. It is essentially a composite slope runup procedure relying heavily on data developed by the Corps of Engineers for presentation in the "Shore Protection Manual." The FEMA computer program "Wave Runup," Version 2.0 was employed for this study.

An erosion assessment must be performed at each location investigated prior to initiating the wave height and runup procedures referenced above. Coastal sand dunes may not be durable due to massive shorefront erosion occurring during a 100-year flood. Storm-induced erosion will remove or significantly modify most frontal dunes on the U.S.A. Atlantic and Gulf shores. Based on the approximate procedure developed by FEMA, in order to prevent dune removal in the 100-year storm, the frontal dune reservoir must typically have a cross sectional area of at least 540 square feet. If a dune has a frontal dune reservoir less than 540 square feet, storm induced erosion can be expected to obliterate the existing dune with sand transported both landward and seaward.

b. Methodology. The first step in conducting the hydraulic analysis for this study was to perform a thorough review of relevant information including the "Flood Insurance Study (FIS), Town of Mashpee, Massachusetts," dated 5 December 1984, and related backup from wave analysis completed by Anderson Nichols and Company (ANCO) in August 1983. A field investigation was conducted along the entire Mashpee shoreline to become familiar with physical features impacting the flood hazard analysis. A vicinity map of Mashpee and a Transect location map are shown on figures 1 and 2, respectively.

Although the purpose of this study is not to revise the established Mashpee FIS, it was necessary to determine the effect of the latest FEMA wave height, wave runup, and erosion criteria on existing flood zones in order to form a basis for comparison of hypothetical sea level rise scenarios. The ANCO analysis was completed prior to implementation of the latest FEMA procedures; therefore, we determined that alone it would not be an adequate reference data base.

The base flood or 100-year stillwater level used for existing conditions was that presented in the Mashpee FIS. This level is in agreement with more recent studies conducted by the Corps of Engineers and presented in "Tidal Flood Profiles - New England Coastline," September 1988. Levels used for existing and sea level rise scenarios are shown in table 1. Sea level rise conditions were developed in even foot increments to simplify the hydraulic analysis. This assumption is consistent with the relative uncertainty in predicting future sea level with the goal being to cover the range of predictions made by the research community.

TABLE 1

MASHPEE SEA LEVEL RISE INVESTIGATION
BASE FLOOD LEVELS

Sea Level Rise Condition (ft)	100-Year Stillwater Level (ft, NGVD)
0-ORIG[1]	11.0
0-NEW[2]	11.0
1	12.0
2	13.0
3	14.0
6	17.0
9	20.0

Notes: [1] Refers to original 1983 ANCO FIS analysis.
[2] Original analysis modified for latest FEMA criteria.

Each transect was first analyzed for frontal dune erosion conditions. This adjustment to the observed ground elevations was found appropriate for transects 1, 2, 3 and 6. In these areas each transect is fronted by a barrier beach dune along both South Cape and Popponesset Beaches. Since these dunes are already substantially overtopped by the existing base flood stillwater level, the erosion adjustment was relatively straightforward involving projection of an approximate 1 on 50 slope from the representative dune toe. The dune toe was estimated at about elevation 5 feet, NGVD for purposes of this evaluation. Engineering judgement employing insights gained in the field visit reinforced the assumption that significant dune erosion is likely during the 100-year flood. At transect 4, a very high eroding sandy bluff is present in the Maushop Village and New Seabury Estates area. Although continued and accelerated erosion of this area is likely during a 100-year flood today and with future sea level rise, no specific analytical predictive technique was determined to be appropriate for application within the scope of this investigation. Transect 5, along Popponesset Beach, is fronted by what appeared to be a fairly recently repaired or replaced revetment. The entire adjacent area showed significant use of structural erosion control measures such as groins and revetments. Should any of these measures experience undermining and failure during a major flood, significant shoreline erosion could occur. Analysis of the stability of these structural measures is beyond the present study scope. Mashpee Neck, transect 7, receives considerable protection from large ocean waves by the fronting barrier beach. With increased future sea level, erosion may become more problematic as larger waves reach the area due to increased water depth.

In order to conduct the analysis of erosion, wave height, and wave runup for existing and future sea level rise scenarios, some adjustments to the original ANCO transect geometries were necessary. Where discrepancies were found in backup data, assumptions were made based on best engineering judgement. Some transects were extended to accommodate the increased future sea level rise conditions. This was accomplished by extrapolation of the landward slope in conjunction with review of available mapping. For continuity, the offshore wave data determined by ANCO was carried throughout this study. All input and output files from the computer analysis are contained in a magnetic disk at Appendix A.

c. Results. In brief, with future sea level rise, larger and greater waves will be able to progress further landward due to increased water depths. The net result will be a significant increase in wave crest profile and runup elevations. Increased wave energy will contribute toward added propensity for erosion in the coastal zone. Table 2 summarizes hydraulic analysis for each transect. At transects 1, 2, 3 and 6, the elevation range for both A and V zones is shown for each sea level rise condition evaluated. Also displayed is the shoreward migration of the initial "A/V" zone interface. "V" zones contain wave heights at or exceeding three feet, while "A" zones include waves less than three feet. Changes between the "0-ORIG" and "0-NEW" are due to the use of updated computer programs with dune erosion analysis as previously discussed. Substantial shoreward migration of the initial "A/V" zone interface occurs when the ocean stillwater, resulting from sea level rise, overtops Seconsett Island, Great Neck, and Popponesset Island. At transects 4, 5, and 7 where wave runup is the primary factor of interest, the unadjusted height of runup as calculated in the computer analysis is shown. In the following section entitled "Transect Interpretation and Mapping," adjustments to these runup values to account for bluff overtopping are discussed. The increased runup and breaking wave forces will exert significant added erosional pressure especially in unprotected areas like near transect 4. Plots of wave heights and runup for all transects for all cases analyzed are contained in Appendix B.

TABLE 2

SENSITIVITY OF "V" AND "A" ZONE TO SEA LEVEL RISE

TRANSECT 1

SEA LEVEL RISE CONDITION (ft)	V ZONE ELEVATION RANGE (ft, NGVD)	A ZONE ELEVATION RANGE (ft, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (ft)
0-ORIG[1]	17-13	13-11	0
0-NEW[2]	17-13	13-11	-10
1	18-14	14-12	365
2	19-15	15-13	4950
3	21-16	16-14	5071
6	25-19	19-17	5284
9	29-22	22-20	5393

TRANSECT 2

SEA LEVEL RISE CONDITION (ft)	V ZONE ELEVATION RANGE (ft, NGVD)	A ZONE ELEVATION RANGE (ft, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (ft)
0-ORIG[1]	17-13	13-11	0
0-NEW[2]	17-13	13-11	198
1	18-14	14-12	1326
2	19-15	15-13	1984
3	21-16	16-14	2444
6	25-19	19-17	3172
9	29-22	22-20	3280

TRANSECT 3

SEA LEVEL RISE CONDITION (ft)	V ZONE ELEVATION RANGE (ft, NGVD)	A ZONE ELEVATION RANGE (ft, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (ft)
0-ORIG[1]	17-13	13-11	0
0-NEW[2]	17-13	13-11	3221
1	18-14	14-12	3253
2	19-15	15-13	3323
3	21-16	16-14	3393
6	25-19	19-17	3533
9	29-22	22-20	4429

TABLE 2 (continued)

TRANSECT 4

SEA LEVEL RISE CONDITION (ft)	V ZONE ELEVATION RANGE (ft, NGVD)	A ZONE ELEVATION RANGE (ft, NGVD)
0-ORIG[1]	23[3]	23[3]
0-NEW[2]	22	22
1	24	24
2	26	26
3	28	28
6	34	34
9	42	42

TRANSECT 5

SEA LEVEL RISE CONDITION (ft)	V ZONE ELEVATION RANGE (ft, NGVD)	A ZONE ELEVATION RANGE (ft, NGVD)
0-ORIG[1]	21[3]	21[3]
0-NEW[2]	20	20
1	21	21
2	23	23
3	24	24
6	28	28
9	32	32

TRANSECT 6

SEA LEVEL RISE CONDITION (ft)	V ZONE ELEVATION RANGE (ft, NGVD)	A ZONE ELEVATION RANGE (ft, NGVD)	SHOREWARD MIGRATION INITIAL A/V INTERFACE (ft)
0-ORIG[1]	17-13	13-11	0
0-NEW[2]	17-13	13-11	128
1	18-14	14-12	542
2	19-15	15-13	553
3	21-16	16-14	564
6	25-19	19-17	600
9	29-22	22-20	635

TABLE 2 (continued)

TRANSECT 7

SEA LEVEL RISE CONDITION (ft)	V ZONE ELEVATION RANGE (ft, NGVD)	A ZONE ELEVATION RANGE (ft, NGVD)
0-ORIG[1]	21[3]	21[3]
0-NEW[2]	23	23
1	24	24
2	25	25
3	25	25
6	29	29
9	32	32

Notes:

[1] Refers to original 1983 ANCO FIS analysis.
[2] Original analysis modified for latest FEMA criteria.
[3] At these transects wave runup governs analysis. Value shown is unadjusted from runup program. At all other transects, wave height analysis governs.

APPENDIX C
ENVIRONMENTAL EVALUATION

SEA LEVEL RISE EFFECTS ON SALT MARSH
ENVIRONMENTAL RESOURCES BRANCH
SECTION REPORT INPUT

Impacts of Sea level Rise

Salt Marshes

Salt Marsh Vegetation. Before summarizing the effects of sea level rise on salt marshes, a brief description of salt marsh zonation is necessary. Salt marshes are generally classified into two types based on the frequency of tidal flooding and vegetation type. The low marsh, or regularly flooded marsh, occurs roughly between the level of mean high water (MHW) and mean low water. In general, its elevational range is wider where the tidal range is greater (McKee and Patrick, 1988). The dominant vegetation in the low marsh is the tall form of salt marsh cordgrass (Spartina alterniflora). The high marsh, or irregularly flooded marsh, occurs between MHW and the level of the highest astronomic tides. The dominant vetetation types in the high marsh are salt meadow grass (Spartina patens), spike grass (Distichlis spicata), and black grass (Juncus gerardi).

Sea Level Rise Effects. There are three possible outcomes of sea level rise as identified by Orson et al. (1985; cited by Phillips, 1986): marsh expansion when sedimentation exceeds submergence; marsh maintenance if sedimentation balances submergence; and marsh drowning when sediment supply and accretion is less than the rate of coastal submergence (a combination of sea level rise and land subsidence). Marsh drowning is associated with erosion of the seaward edge of the marsh.

Marsh Expansion and Maintenance. A marsh can expand or maintain itself where the sediment supply is sufficient to keep pace with the rate of sea level rise. Nixon (1982), in "The Ecology of New England High Salt Marshes: A Community Profile," summarized the response of salt marshes to sea level rise. According to Nixon, the most recent, and generally accepted, view of how marshes adjust to sea level was described by Redfield (1972) in his classic study of Barnstable Marsh on Cape Cod. This synthesis combines the earlier theories of N.S. Shaler (1886) and B.F. Mudge (1862) on marsh development with new research and an understanding of the role of sea level rise. Nixon summarized Redfield's findings as follows: "With a rising sea level and a sufficient sediment supply...the intertidal S. alterniflora peat extended progressively out from the shore and at an upward slope over an aggrading sand and mud deposit. The high marsh peat then formed over the intertidal peat as a wedge which thinned as it expanded toward the upland and the seaward edge of the marsh." In other words, salt marshes adjust to sea level rise by expanding inland and waterward and increasing in elevation through accumulation of sediments and plant biomass. This process is shown in Figure 1.

Marsh Drowning. In the total absence of surface accretion, the quantity of high marsh would decrease and the low marsh would move up in elevation until high marsh disappeared and the upland slope eventually reached a near vertical level. A fringing salt marsh would develop along the shoreline based on the new tidal range. A rise in sea level would cause a corresponding increase in the elevation of MHW and the highest astronomic tides which delimit the major marsh boundaries. As MHW moved up in elevation, the low marsh/high marsh border would migrate accross the high marsh until the high marsh drowned from too high a frequency of flooding. When the level of MHW exceeded the elevation of the highest existing area of high marsh, no high marsh would remain. While migrating up in elevation, the seaward limit of the low marsh would be exposed to increased erosional forces preventing the low marsh from increasing in size laterally. Eventually, the low marsh too would be overtaken by the frequency of flooding until only open water remained. When the level of MLW exceeded the elevation of the low marsh, low marsh would no longer remain.

There are other factors, interrelated with sediment availability, which affect the ability of a salt marsh to keep pace with sea level rise: 1) erosion at the seaward edge, 2) slope of the adjacent upland, and 3) the rate of sea level rise. The quantity of channels, ditches, and pannes on a marsh also influences the ability of the marsh to keep pace with sea level rise (Phillips 1986).

Erosion of the seaward edge limits the ability of the marsh to grow outward. The amount of erosion on the seaward edge of the marsh is difficult to determine but is dependent on the amount of sea level rise and the rate at which new sediment is supplied. If the rate of sea level rise exceeds the rate of accretion, the seaward edge of the marsh will erode. That material eroded from the edge will be spread across the marsh surface to increase its elevation (Reed, 1988). Bruun (1962) developed a method now known as the Bruun Rule to determine the erosion rate due to sea level rise. As summarized by Phillips (1986), "The Brunn Rule holds that, for a shoreline in longshore equilibrium, a given rate of sea level rise will result in shoreline erosion sufficient to deposit sediment in the nearshore zone to a depth equal to sea level rise." (The nearshore zone is the zone along the shore affected by waves.) The quantity of material eroded from marsh edges would have to be sufficient to cover the nearshore area, which has a width that expands with erosion, minus sediment input from outside of the marsh, for the seaward edge of the marsh to maintain or expand its lateral extent before marsh accretion can occur.

A given erosion rate under each of the sea level rise scenarios would require an increasingly greater accretion rate to maintain the marsh area where the slope of the adjacent upland is greater (Phillips, 1986). Where seawalls or bulkheads are constructed along the shoreline, the slope is considered to be very steep. Assuming that the sediment supply is not sufficient to supply the marsh surface and the nearshore zone at a rate that will allow the marsh to keep pace with sea level rise, erosion of the seaward edge of the marsh will occur. With an erosion rate caused by sea level rise which is constant, the accretion rate would have to be higher to maintain the existing marsh area where the upland slope is greater (Phillips, 1986). The accretion rate is dependent on marsh flooding, however. Those areas that are more frequently flooded, in general, have a greater ability to accrete. To keep pace with the erosion rate, the accretion rate would have to exceed the rate of sea level rise. While this can occur (Nixon, 1980), it is not likely to maintain the marsh over the long term.

Expansion of salt marsh in Mashpee would most likely occur into areas now dominated by fresh water-brackish marsh and shrub/forested swamp along the salt marsh/upland edge since these areas often gradually transition into salt marsh in contrast to steeper upland slopes. This would simply be a response to the increase in fooding and salinity levels. It would result in a reduction in the amount of tidal fresh water and brackish marsh. No accretion would be necessary to maintain these areas as wetland until the level of mean high water exceeded the level of these marshes.

Effects on the Marshes of the Town of Mashpee. Assuming no sediment is added, assumptions can be made about the fate of salt marshes in Mashpee. The difference between the mean tide range and the spring tide range at Poponesset Bay in Mashpee is 0.5 ft. (NOS, 1992). Using this as a rough estimate of the vertical range of high marsh (accounting for the high marsh range to the highest astronomic tide level), all high marsh would be eliminated with a 0.5 ft. rise in sea level. Assuming that the low marsh extends from MLW to MHW (mean tide range) a vertical extent of 2.3 ft., all low marsh within the footprint of existing salt marsh would not be eliminated until sea level rise exceeded 2.8 ft. With 3 to 9 feet of sea level rise only open water and a thin salt marsh fringe would be present. However, as previously discussed, salt marshes can adjust to sea level rise with sediment input.

Since the ability of a marsh to keep pace with sea level rise is dependent on sediment supply, site-specific analyses of the watershed and coastal sediment inputs would be required to determine the reaction of the marshes in Mashpee to sea level rise. Without site-specific analysis, it is expected that the elevation of the marsh surface could keep pace with the historic rate of sea level rise (2.3 mm/yr; 1 ft/100yr). Generally salt marshes have been able to keep pace with sea level rise of this magnitude (Nixon, 1982; Reed, 1988). It is not possible to estimate the effects of sea level rise of 2 or 3 feet under the level of effort for this study, although in general the higher the rate of sea level rise the greater the liklihood of marsh drowning.

Under the 6 ft/100 yr (18 mm/yr) and 9 ft/100 yr (27 mm/year) sea level rise scenarios, major reductions in the area of salt marsh would most likely occur since the quantity of sediment input would have to be very high. However, if the sediment supply were sufficient, the marsh could probably adjust to even these extreme rates of sea level rise (Nixon, 1982).

Effects at the Study Transects. Assumptions can be made about the effect of sea level rise on the salt marshes of Mashpee at the study transects. Transects 1, 2, and 3 for this study pass through salt marsh. Transect 1 passes through the southernmost tip of Seconsett Island. The salt marsh here appears to be highly suceptable to erosion with sea level rise. Phillips (1986) found that pennisular points such as this in Deleware experienced rapid truncation with sea level rise. The portion of Transect 1 north of Hamlin Pond crosses a fringing salt marsh adjacent to a fairly steep upland slope. Loss of aerial extent would be more likely here if extreme sea level rise causes erosion of the seaward edge and the sediment supply is not sufficient to maintian the existing area at an increasing elevation. Those portions of Transects 2 and 3 that pass through salt marsh are located in areas with shallow slopes; these areas would be most capable of adjusting to sea level rise without losing salt marsh area.

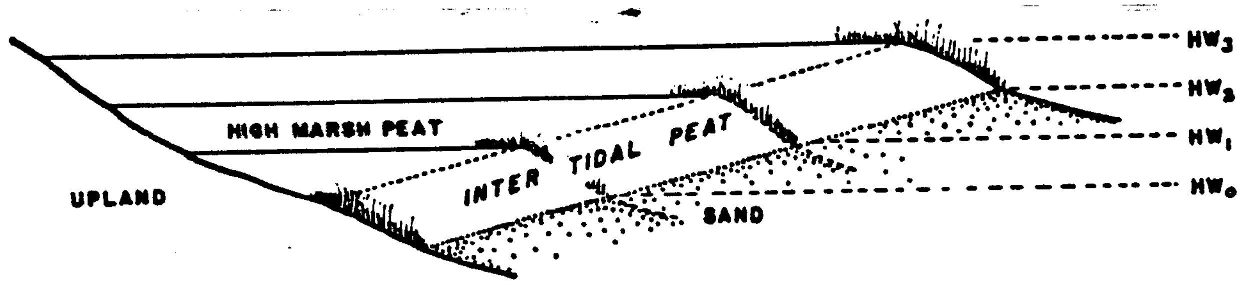


Figure 5. Redfield's model for salt-marsh development over accumulating sediment on a sand flat and over the upland under the influence of rising sea level (Redfield 1972). HW refers to mean high water at various times during development.

FIGURE 1. From Nixon, 1982, The Ecology of New England High Salt Marshes: A Community Profile.

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